FLEET TECHNOLOGY LIMITED
A FLEET AEROSPACE COMPANY

# DESIGN AND CONSTRUCTION OF AUTOMATED FREEZE-THAW TESTING EQUIPMENT FOR CONCRETE

FINAL REPORT

BY

FLEET TECHNOLOGY LIMITED,
(formerly ARCTEC CANADA LIMITED),
311 Legget Drive,
Kanata, Ontario.
K2K 1Z8

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PROJECT TEAM:

Dr. Aly M. Nawwar
Mr. Tim Roots
Mr. Dave Frere
Mr. Rob Nelson

APPROVED BY: _____

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## 1. INTRODUCTION

Cycles of freezing and thawing can be extremely destructive to concrete structures. Continued research into more appropriate materials for use in severe environments has created a need for systematic testing of concrete samples exposed to this action.

In Canada, freeze-thaw testing is conducted in accordance with the American Society for Testing and Materials (ASTM) Standards C666 and C671. These standards specify the thermal cycle envelope to be followed as well as methods for detecting sample failure.

Testing machines have been constructed for this purpose and are commercially available. Present machines, however, have been designed to subject concrete samples to thermal cycling only. Critical measurements such as change in length and resonant frequency must be performed by trained technicians in controlled environments. This has proven to be costly and labour-intensive and can also increase the difficulty in maintaining the ASTM standards.

The objective of this project is to study the feasibility of designing and constructing an automated freeze-thaw testing machine. This machine would incorporate all aspects of freeze-thaw testing while ensuring that standards set forth in ASTM C666 are met.

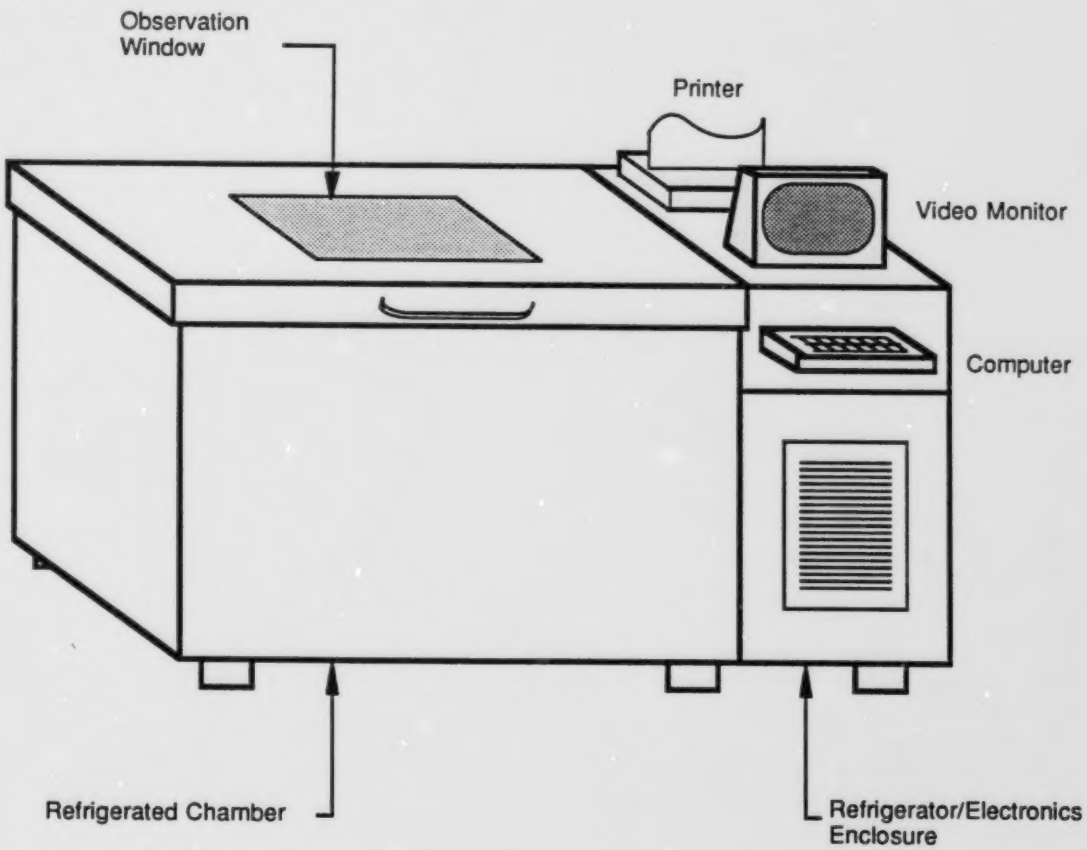
## 2. CONCEPT DEVELOPMENT

The initial concept for the freeze-thaw machine was that it expose between four and six concrete specimens to the temperature cycling required by ASTM standard C666-80, and also that it record all measurements required by this standard. Both measurements and temperature cycling were to be performed automatically under computer control. In addition to the resonant frequency measurement required by the standard, a requirement of CANMET was that the machine be able to measure changes in length of the concrete specimen. The results of each measurement were to be printed together with the date, time and number of cycles elapsed. A conceptual drawing of a freeze-thaw machine is shown in Figure 2.1.

The functions of the freeze-thaw machine were divided under the three main headings of temperature cycling, specimen property measurement, and system control. The temperature cycling requirement, shown in Figure 2.2 was to be repeated up to 36 times between each set of measurements. Temperature cycling was also to be carried out while the concrete specimens were immersed in water, and the water drained before measurements were made.

In order to expose the concrete samples to the specified thermal cycles, an insulated test chamber with heating and cooling systems of sufficient capacity was required.

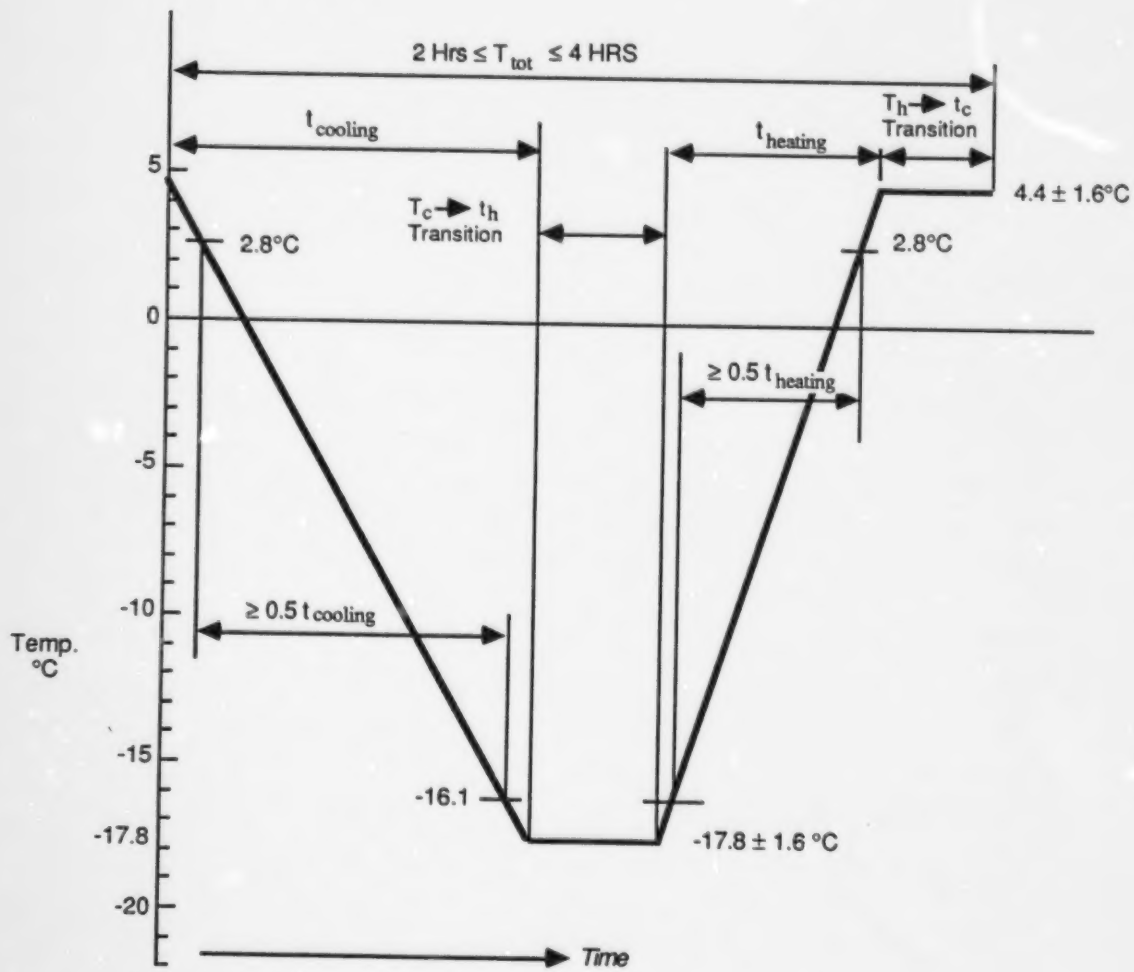
**Figure 2.1 Conceptual Apparatus**



## Figure 2.2

### Temperature Cycle Required by ASTM Standard C666-80 For Freeze-Thaw Testing of Concrete

Concrete core temperature is indicated




*Notes:*

1) $t_{heating} \geq 0.25\, t_{cooling}$

2) $t_c \rightarrow t_h$ and $t_h \rightarrow t_c$ transitions may not exceed 10 mins.

3) Measurements to determine Fundamental Frequency should be conducted at intervals of not more than 36 cycles.

Measurement equipment of appropriate type and with sufficient accuracy and resolution had to be specified. The size and space requirements of these instruments had to be considered while establishing the dimensions of the test chamber. CANMET requirements for length change measurements specified that an instrument capable of detecting a length change of at least 0.1% be incorporated. The ASTM standard required that the resonant frequency of the concrete specimens be determined such that changes in the relative dynamic modulus of elasticity could be observed. A reduction in the resonant frequency or a change in length would indicate deterioration of the concrete. The most suitable method of performing these measurements was to be selected.

In order for the freeze-thaw machine to operate automatically a system was required to control the thermal cycling, the filling and draining of water in the containment boxes, the mechanisms required for the length and resonant frequency measurements, the acquisition of measurements and reporting of the results. In addition, the control system had to accept input commands to change cycle times, temperature set points, or other operational parameters.

The concepts described above for a freeze-thaw machine required delineation and development before a complete, detailed design could be produced. The following sections describe this development process.

## 2.1 Temperature Cycle Thermal Analysis

In order to determine the thermal loads on the heating and cooling systems, two methods of calculating the amount of heat which had to be removed from or added to the concrete during the temperature cycle were utilized. The first method, based on the principles of conservation of energy, calculated the total amount of heat which had to be removed and provided an initial estimate of the required cooling capacity. This calculation (Appendix C) indicated a total heat change of 2732 KJ (2589 BTU).

The second method used finite element models to establish temperature gradients within the concrete. This method calculated the temperature requirements for the cooling cycle, and the maximum power required for heating. It was also necessary to determine the concrete sample's surface and core temperature difference as this must not exceed 20°C.

The finite element method is described fully in Appendix C and the results are summarized here. Calculations were performed separately for the heating and cooling portions of the cycle. During the heating cycle, when the concrete temperature was raised from -17.8°C to 4.4°C, the concrete block and containment box were arranged as shown in Figure 2.3. The initial temperature conditions and heating power inputs are indicated in Table 2.1. The results showed that the ambient temperature in the chamber had a major effect on the temperature gradient and heating times. Table 2.2 compares these initial conditions with the calculated results.

## Figure 2.3

## Concrete Block and Containment Box Arrangement Assumed For Thermal Analysis

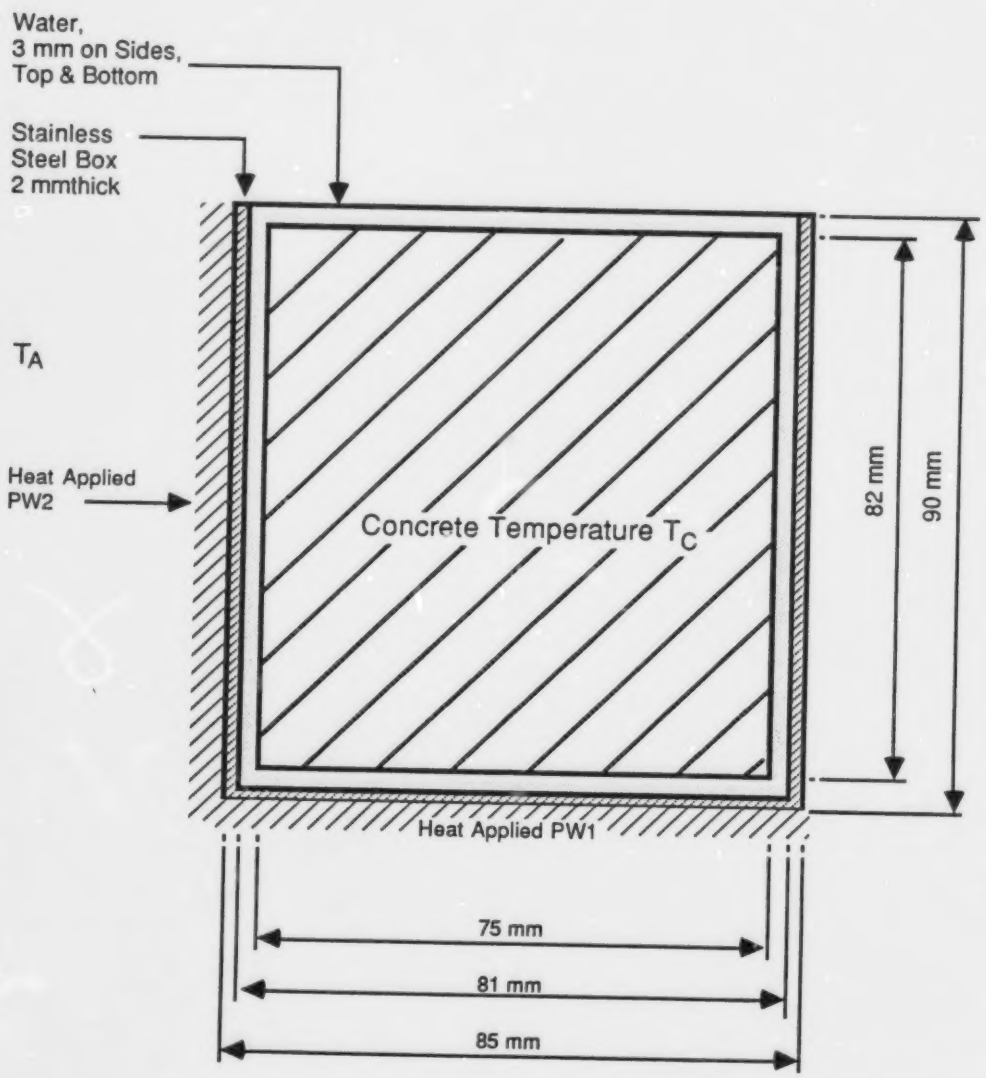


TABLE 2.1

INITIAL CONDITIONS AND PARAMETRIC VARIATION DURING THERMAL ANALYSIS

a) **Heating Phase - Initial $T_{concrete}$ = -17.8°C**

| INITIAL CONDITION | $T_{ambient}$ | HEATING POWER (applied on bottom) $kW/m^2$ | HEATING POWER (applied to sides) $kW/m^2$ |
|---|---|---|---|
| 1 | -25°C | 6 | 0 |
| 2 | 0°C | 3 | 0 |
| 3 | 0°C | 1.25 | 0 |
| 4 | +10°C | 1.25 | 0 |
| 5 | 0°C | 0 | 0.4 |

b) **Cooling Phase Initial $T_{concrete}$ = 4.4°C**

| INITIAL CONDITION | $T_{ambient}$ | SURFACE CONVECTION COEFFICIENT $W/m^2$ | TEMP. RANGE FOR LATENT HEAT ABSORP. | WATER OR ICE ON TOP SURFACE |
|---|---|---|---|---|
| 1 | -25°C | 12 | +4.4 → -17.8°C | W |
| 2 | -25°C | 12 | 0 → -17.8°C | I |
| 3 | -20°C | 12 | 0 → -17.8°C | I |
| 4 | -25°C | 30 | 0 → -17.8°C | I |
| 5 | -20°C | 30 | 0 → -17.8°C | I |

TABLE 2.2

HEATING TIME AND TEMPERATURE GRADIENT
FOR CONCRETE DURING HEATING HALF CYCLE

| INITIAL CONDITION | $T_{AMB}$ | HEATING POWER $KW/m^2$ | MAX. TEMP. SPREAD °C | TIME TO REACH 4.4°C |
|---|---|---|---|---|
| 1 | -25°C | 6 | 70°C | $\geq$ 90 min. |
| 2 | 0°C | 3 | 41 | 60 min. |
| 3 | 0°C | 1.25 | 21 | 75 min. |
| 4 | +10°C | 1.25 | 19 | 40 min |
| 5 | 0°C | 0.4 | 9 | 45 min |

TABLE 2.3

COOLING TIME REQUIRED FROM +4.4°C to -17.8°C

| INITIAL CONDITION | $T_{amb}$ °C | CONVECTION COEFFICIENT $h_c$ $W/m^2$ | TIME REQUIRED min. |
|---|---|---|---|
| 1 | -25 | 12 | >90 |
| 2 | -25 | 12 | >90 |
| 3 | -20 | 12 | >90 |
| 4 | -25 | 30 | 37 |
| 5 | -20 | 30 | 58 |

Based on this, the heating power chosen was 1 $KW/m^2$ of contact area. The heaters were positioned at the bottom of the containment box in order to make installation easier and to provide reasonable temperature gradients within the sample. It was assumed that the ambient temperature within the refrigerated compartment could rise to 10°C during the heating half cycle, which was estimated to take 30-45 minutes.

The conditions utilized during the cooling phase calculations are also tabulated in Table 2.1. The geometrical configuration of the concrete block and containment box was the same as that utilized during the heating phase calculations. The ambient temperature and the ice surface to air convection coefficient were varied. The latter was varied in order to simulate the effects of free (12 $KW/m^2$) or forced (30 $KW/m^2$) convection.

This analysis showed that forced convection was necessary to provide an adequate cooling rate. With a chamber temperature of -20°C, the time required to lover the core of the concrete to -17.5°C was 58 minutes. At this cooling rate the difference between the maximum and minimum temperature within the sample was less than 5°C. Cooling times for the different conditions analyzed are shown in Table 2.3.

The thermal analysis showed that a heater input of no more than 1 $KW/m^2$ was required on the bottom of the concrete specimens. This ensured that temperature gradients within the concrete did not exceed the 20°C maximum established in standard C666-80. Conditions of forced convections were needed to ensure an adequate heat transfer rate. Under these conditions the heating time from -17.8° to +4.4°C was predicted to be less than one hour while cooling from +4.4° to -17.8°C was expected to require about one hour.

It should be noted that the above time estimates were based on assumed coefficients and idealized modelling of the concrete containment system. These estimates are, however, sufficient to indicate general compliance with ASTM standard test procedures.

## 2.2 Length Measuring System

The measurement of the length of the concrete samples is not an ASTM requirement. However, this measurement provides a good indication of the condition of the concrete undergoing freeze-thaw cycling, and that failure is indicated by a cumulative change in length exceeding 0.1%. Standard concrete specimens used in freeze-thaw testing are approximately 400 mm in length. The measurement system must therefore be able to detect a change in length of about 0.4 mm. In order to detect this change of length the measuring instrument should have a minimum resolution of no more than 5% of the total measurement, i.e. 0.02 mm or 20.0 microns.

Several methods of measuring length changes were assessed. These included:

1. Proximity probes
2. Flexure element
3. LVDT probes
4. Laser methods
5. Optical methods

In Table 2.4 the accuracy, cost and provision for automation of these five measurement methods are summarized. Three of these methods (Laser, LVDT, and Eddy current probes) met the prescribed accuracy and resolution requirements. However, the Laser was discarded due to its high cost ($15,000+). An assessment of the relative merits of the eddy current proximity probe and the LVDT follows. Typical examples of these instruments are shown in Figure 2.4.

Eddy Current Proximity Probe:

The eddy current proximity probe is a non-contacting electromagnetic device which is capable of detecting the presence and position of metallic objects.

A typical device which is available on the market is the KAMAN 2310, specifications of which are found in Appendix A. The accuracy of this probe at a measuring range of up to 6 mm is 0.0006 mm, which is sufficient resolution to measure the growth of the concrete.

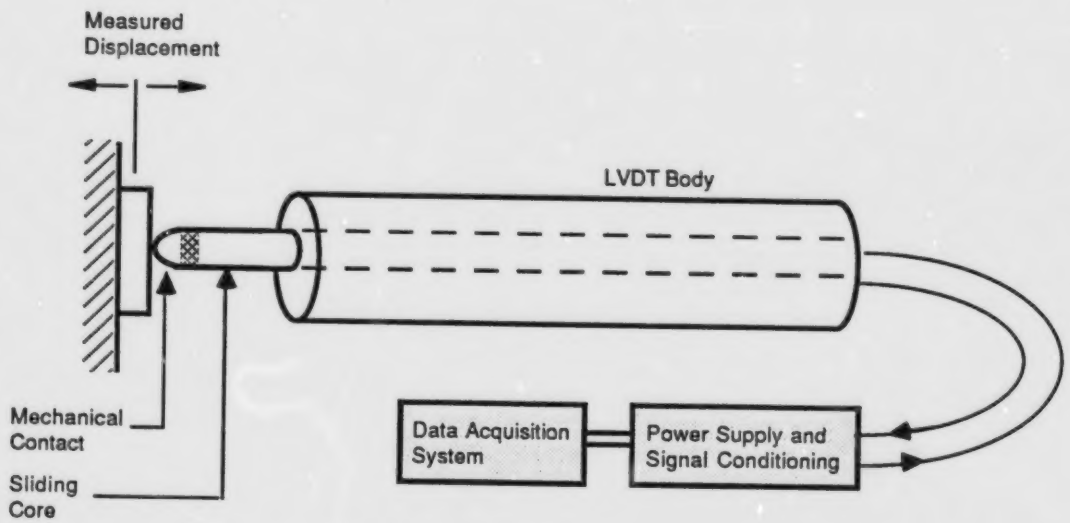
The primary drawback to the use of an eddy current probe is that the probe is not only sensitive to the distance from the probe to the target, but also to the orientation of the target relative to the probe. Changes in the angular, longitudinal or transverse orientation of the target and probe will affect the output. In order to obtain reliable results this would require that one probe be used at each end of each specimen for a total of twelve probes. The cost of this solution would be too great.

TABLE 2.4

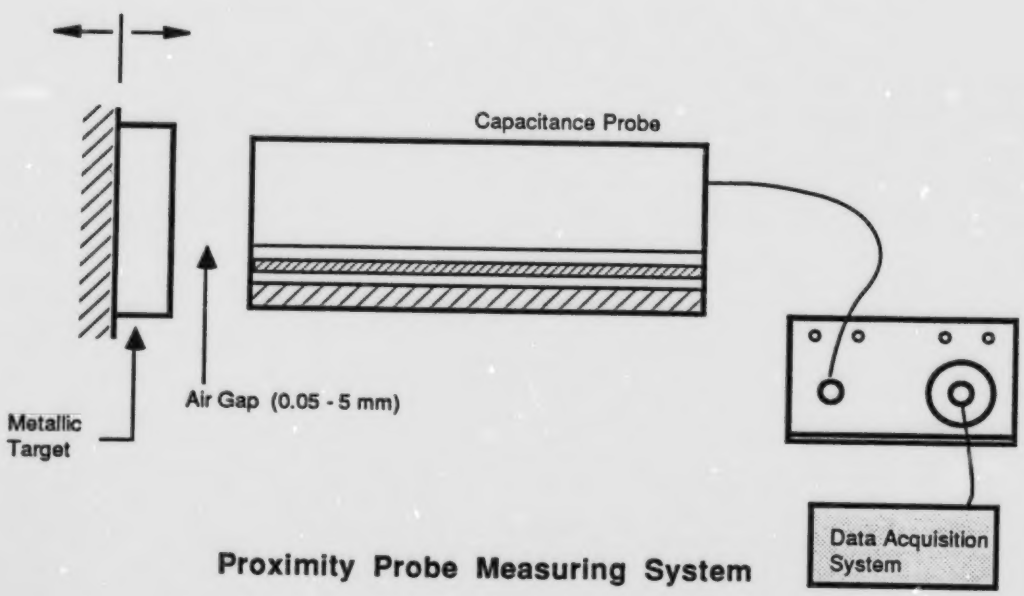
COMPARISON OF LENGTH MEASUREMENT METHODS

| MEASUREMENT METHOD | ACCURACY | ABILITY TO BE AUTOMATED | COST PER MEASURING HEAD | ADDITIONAL HARDWARE REQUIRED | NON CONTACT OR REMOVABLE CONTACT |
|---|---|---|---|---|---|
| 1. LVDT Probe | 0.0001mm | Excellent | $950.00 | Signal Conditioner $600.00 | Yes |
| 2. Proximity Probe | 0.006mm | Excellent | $1200.00 | Power Source & Signal Cond. $1000.00 | Yes |
| 3. Flexure Element | 1 mm | Excellent | $500.00 | Signal Cond. $100.00 | No |
| 4. Laser Head | 0.00001 m | Excellent | $15,000.00 | Large number of system components | Yes |
| 5. Optical Methods | 0.01 m | Poor | $40,000.00 | - | Yes |

**Figure 2.4 Length Measurement Methods**




**LVDT Measuring System**




**Proximity Probe Measuring System**

LVDT:

An LVDT (Linear Variable Differential Transformer) probe is a displacement transducer of high accuracy and resolution (0.0001 mm). It consists of a fixed tubular body containing two coils and a movable ferro-magnetic core. An AC current applied to one coil is magnetically coupled to the second coil, which produces a signal proportional to the core's position.

This device must physically contact the specimen in order to measure any changes in length (see Figure 2.5). Some method had to be devised such that the probe could be made to contact the end of each specimen, and also be retracted during resonant frequency measurements. Also, to reduce costs, a single probe could be used to measure each specimen, if it were mounted on a moving carriage.

Using the LVDT in a caliper, the alignment with respect to each concrete specimen was not critical and could be met by the use of good bearings and a controllable drive system.

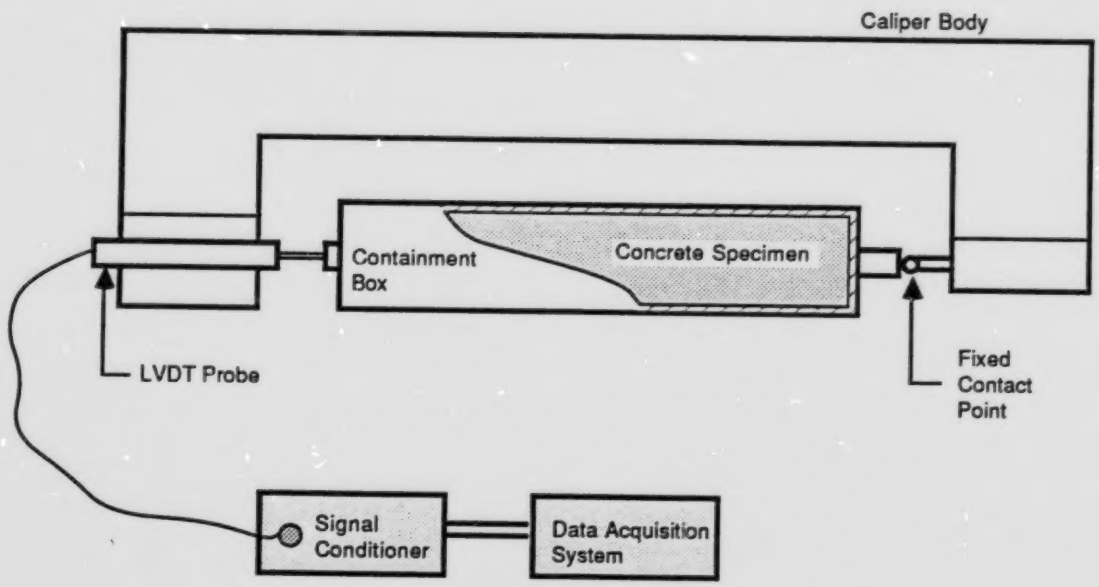
Based on this investigation into the range of methods which could be used to measure the length of the concrete specimens accurately and economically, the best solution appeared to be the use of an LVDT. By mounting the LVDT in a moving caliper, one LVDT could be used to make measurements on all the specimens thereby providing a measurement of sufficient accuracy at a relatively low cost.

## 2.3 Resonant Frequency Measurement

A requirement of ASTM standard C666-80 is that the dynamic modulus of the concrete specimen be measured. The recommended method of measuring this is to measure one of the resonant frequencies of the concrete, either longitudinal, transverse or torsional. The standard specifies that the resonant frequency be measured by exciting the concrete specimens using a sinusoidal external force over a range of frequencies, and recording when the concrete prism enters resonance in its first mode of vibration.

Two methods of inducing vibrations in the concrete specimen were evaluated. The first method was to use an electromagnetic vibrator capable of providing forces of about 100N at frequencies up to 12 kHz. This method employs standard equipment used by other manufacturers of resonant frequency testing machines. The drawback to this system was that the cost of the vibrator and associated driving electronics was high. A much simpler method of vibrating the concrete block at its resonant frequency would be to provide an impulse of "white noise" by tapping the block with a light object such as a small hammer. This impulse would cause the block to vibrate at its natural frequency for a brief period of time. An experiment was performed to determine the viability of this method using an accelerometer and oscilloscope to measure the response of the concrete. These tests showed that a light tap such as could be provided by a pencil would provide vibrations of sufficient amplitude and duration to determine their frequency.

**Figure 2.5 Length Measurement Calipers**



The selected method of inducing vibrations was the electromagnetic vibrator because it conformed fully to the requirements of the ASTM Standard C666-80, while the impulse method did not. This standard required that a frequency sweep be made both above and below the resonant frequency, which could not be done using the white noise method.

In order to determine the resonant frequency of the concrete through a frequency sweep it is necessary to measure the amplitude with which the concrete vibrates at each frequency. Theoretically this measurement could be either displacement, velocity or acceleration. The possibility of making a displacement measurement was investigated, but this measurement was shown to be more difficult. The amplitude of the displacement of a concrete block of appropriate dimensions was calculated under a 100N load, and found to be $1 \times 10^{-6}$m or 1 micron, which is not sufficient for any deflection measuring instruments considered.

The most straightforward means of making amplitude measurements was to use a general purpose piezo-electric accelerometer. These instruments typically operate between 0.5 and 20 kHz with a sensitivity of 100-mV/g, making them very suitable for this measurement. Accelerometers are also easily available at a moderate cost.

The technique which was selected for the measurement of resonant frequency consists of an electromagnetic vibrator used to induce vibration and an accelerometer to measure the amplitude. Figure 2.6 is a schematic illustration of the resonant frequency measuring system.

## 2.4 Measuring Carriage

The concept developed for recording displacement and vibration measurements required a single set of measuring instruments. These instruments would be moved between samples to record the measurements on each sample in turn. In order to do this, movement along two axes was required. The accelerometer and vibrator for measuring vibration had to be lifted away from the specimens to clear the containment boxes as well as be moved horizontally between the concrete specimens. The caliper for measuring length only had to be moved horizontally.

A method for moving the measuring instruments was developed based on a simple X-Y positioning table. This concept, shown in Figure 2.7 consists of a vibration measuring platform, attached to a second carriage, which would also carry the length measuring caliper.

## Figure 2.6 Frequency Measurement Concept

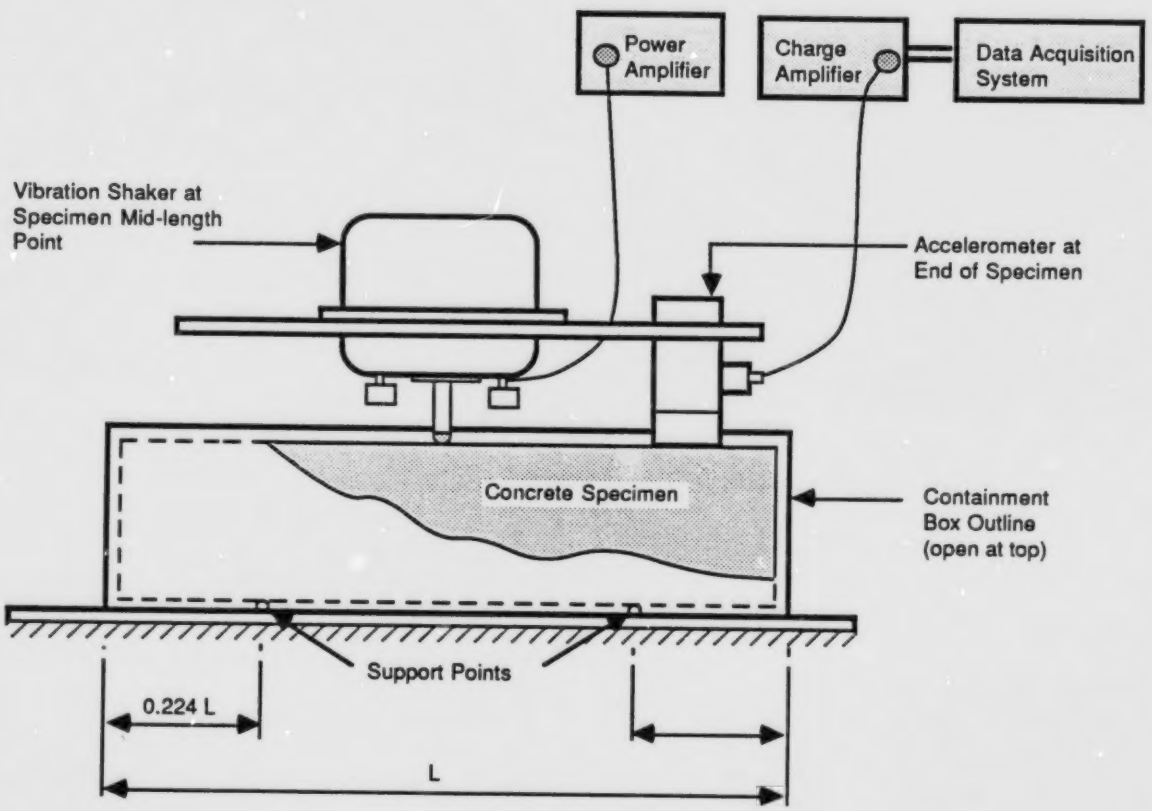
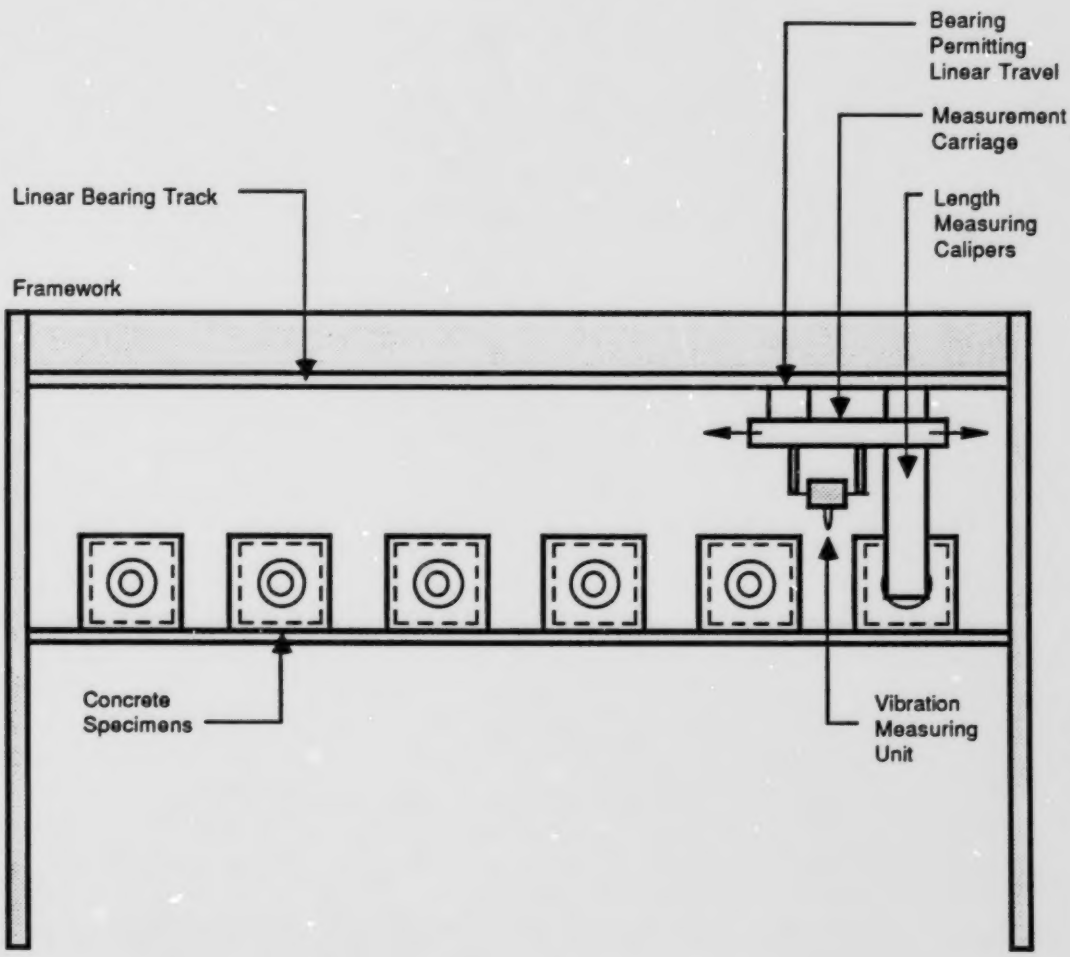


**Figure 2.7 Measuring Carriage and Concrete Specimens**



## 2.5 Electronic Control System

The requirements for an electronic control and measurement system can be divided into the following sections:

- Process control
- Signal conditioning and acquisition
- Data processing
- System management

Processes such as thermal cycling, water filling and draining, carriage motion and instrument actuation had to be sequenced and controlled in an orderly fashion.

The signals from various sensors needed to be amplified, and transformed into a format readable by the controlling system. As well, actuators and sensors required excitation signals of appropriate magnitude.

The acquired signals could then be used as feedback to the controller as well as to determine resonant frequencies and length changes for each sample.

The electronic control system controlled the operation of all aspects of the testing machine as well as accept different test parameters from the operator, determine the onset of failure of any sample and report test results.

A desktop computer complete with keyboard, video screen, printer, disc drive, and interface boards along with a data acquisition system and supporting circuitry was determined to be a cost effective solution.

Such a system could be programmed in a high level language making software development and maintenance more manageable.

## 3.0 DETAILED DESIGN

Detailed design of the freeze-thaw machine consisted of developing working drawings and specifying all mechanical and structural components.

A brief description of the detailed design and component selection criteria are provided in the following sections.

### 3.1 Temperature Cycling Systems

Heating System:

The thermal analysis described in section 2.1 determined that the heat input requirement was approximately 1 kW/$m^2$ of contact area. This area has dimensions of approximately 410 x 80 mm and a surface area of 0.036 $m^2$. The calculated power requirement per concrete specimen is 36 W and was provided by a strip heater under each specimen. The heater and containment box arrangement are shown in Figure 3.1.

Refrigeration System:

The chamber conditions required to provide the correct cooling for the concrete specimens was an ambient air temperature of -20°C with forced convection. The total heat to be removed from the concrete, surrounding water and structure during the cooling cycle was calculated to be 2732 KJ. In addition to the cooling requirements of the concrete specimens, heat losses through the chamber walls and through connections were considered. Losses through the walls were calculated to be 9.16 W (Appendix C) or 33 KJ/hr and losses through connections such as wiring, plumbing and the seal around the door were estimated to be ten times this, or 100 W. The sum of all cooling losses was assumed to be 110 W or 363 KJ/hr, 15% of the concrete cooling load. The total cooling load was predicted to be 3095 KJ/hr or 0.86 W (2570 BTU/hr), assuming one hour of cooling as predicted by thermal analysis.

Although the maximum heat flow predicted by thermal analysis was in excess of this capacity, the calculation assumed a minimum temperature of -20°C. In actuality the temperature would drop from +6°C to below -20°C while the concrete cooled. As a result, the maximum heat flow would be reduced but the final heat flow at the end of the cooling cycle would be increased. These two effects were assumed to cancel, therefore the total cooling time would not change greatly.

The choice of refrigeration systems was limited to either 0.67 kW or 1 kW models with cooling capacities of 0.76 kW or 1.35 kW at -23°C respectively. The less powerful model was selected, as it appeared to be capable of providing a cooling time of 1.13 hrs, well within the 2 hrs permitted for cooling. Brief specifications for this refrigeration system are provided in Table 3.1.

FIGURE 3.1

Containment Box / Heater Arrangement

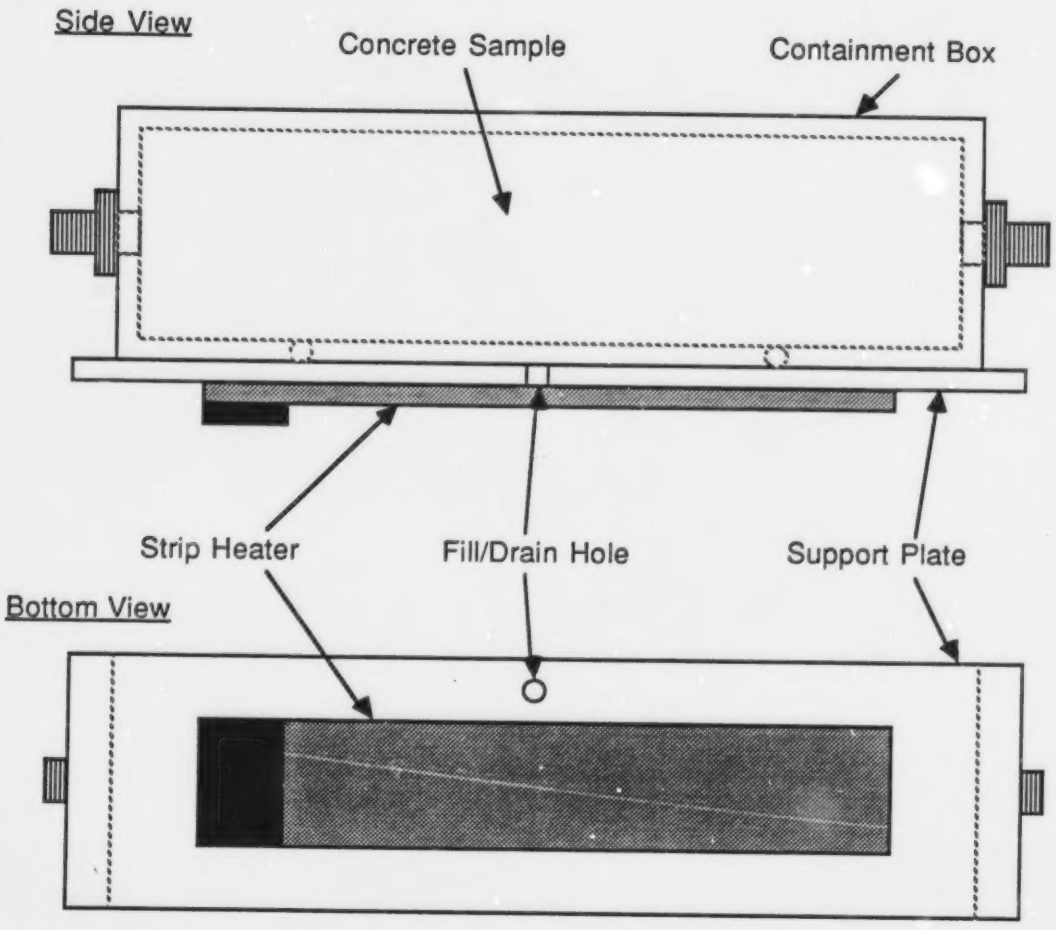


TABLE 3.1

REFRIGERATION SYSTEM

COMPRESSOR: Copeland Coplemetic EBAL 0052

| | |
|---|---|
| Motor Power: | 373 W |
| Voltage: | 230 V |
| Capacity: | 2600 BTU/hr @ -23°C |
| Refrigerant: | R502 |
| Dimensions: | L x W x h (mm): 521 x 400 x 343 |

EVAPORATOR: Keeprite Model TW300ED

| | |
|---|---|
| Airflow: | 0.20 $m^3/s$ |
| Fan Motor Power: | 30 W |
| Voltage: | 115 V |
| Capacity: | 512 KJ/h@°C |
| Dimensions: | L x W x h (mm): 548 x 479 x 146 |

## 3.2 Measuring Components

The LVDT , vibration exciter and accelerometer were selected in accordance with the criteria developed during the concept design. In addition, component mounts were designed to allow proper measurements to be taken.

Length Measurement:

The detailed design of a caliper containing an LVDT is shown in Figure 3.2. The concrete specimen length is measured between the LVDT located on one arm of the caliper and a fixed pointer located on the other arm. In its open position the caliper is about 6 mm longer than the concrete specimen and can move between specimens. To take the measurement, the caliper is closed by sliding the entire caliper along the linear bearing track supported from the main carriage. The caliper is moved until the pointer contacts the end of the concrete specimen. To complete the measurement the LVDT measuring head is brought against the opposite end.

Movement of the caliper and LVDT measuring head is provided by pneumatic cylinders, one mounted at the top of the caliper, the second forming part of the LVDT.

Resonant Frequency Measurement:

In order to measure the resonant frequency of the specimens it was necessary to mount the accelerometer and vibration exciter in such a manner that they could be brought into contact with the concrete from above. In addition it was desirable to isolate the vibration exciter from the accelerometer such that the accelerometer would only measure the acceleration of the concrete.

The design of the measuring platform which carries the vibration exciter and accelerometer is shown in Figure 3.3. The vibration exciter is mounted in a position where it contacts the concrete specimen midway between the specimen support points. A flexible diaphragm is used to isolate the carriage from the vibration exciter. The accelerometer is mounted within a sliding tube positioned to measure vibrations in the end of the specimen. The accelerometer is held against the concrete specimens under pressure from a coil spring.

Vertical movement of the measuring platform is provided by a pneumatic cylinder. Motion of this platform is mounted by nylon bushings and stainless steel shafts. The vibration exciter used on this apparatus is a Ling model 100, providing an exciting force of 100N at frequencies from 0 to 12,000 Hz. The oscillator and amplifier used for its control are discussed fully in Section 3.6, (Electronic Design). The accelerometer is a Dytran model 3100. Full specifications of all equipment are included in Appendix A.

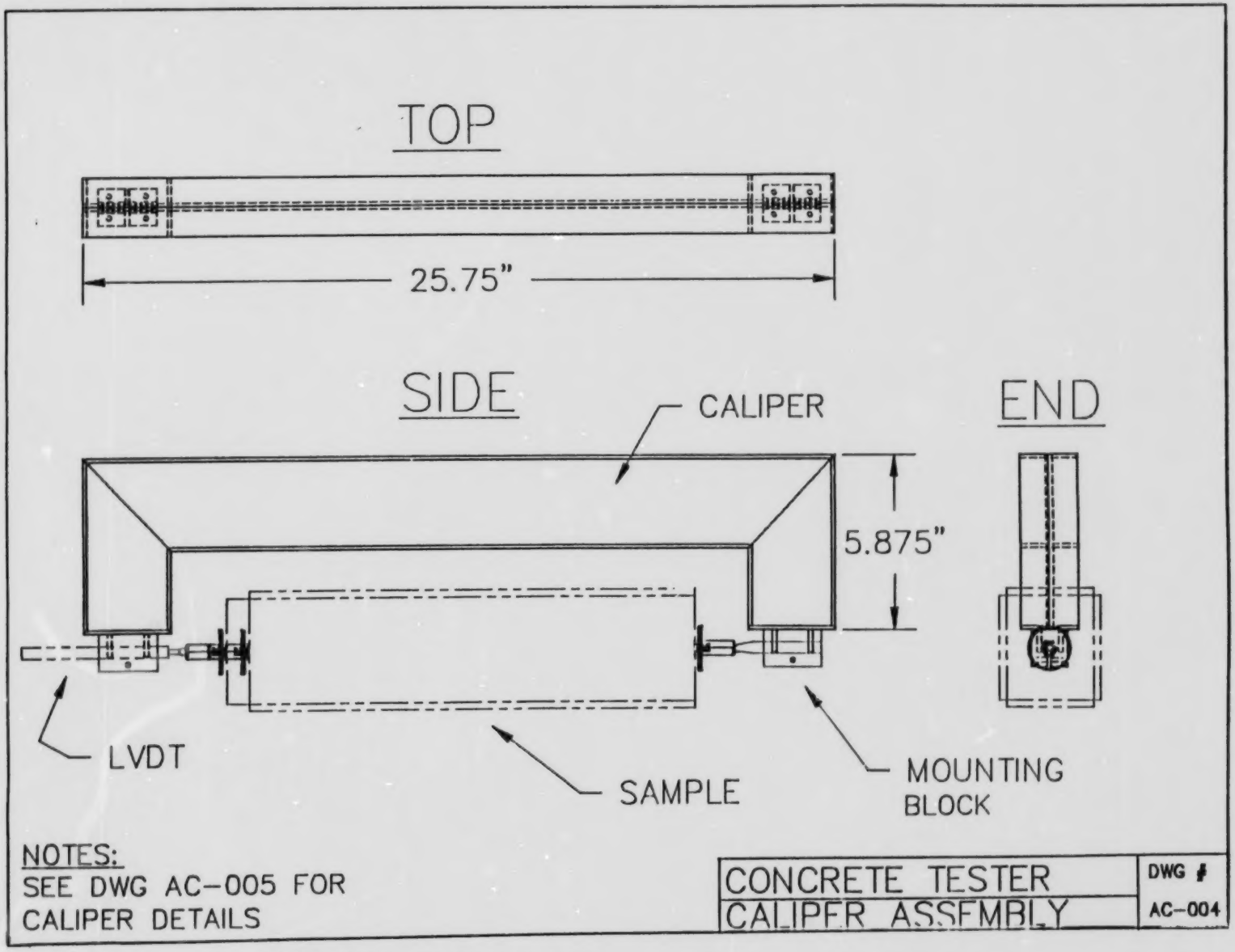



FIGURE 3.2 CALIPER ASSEMBLY

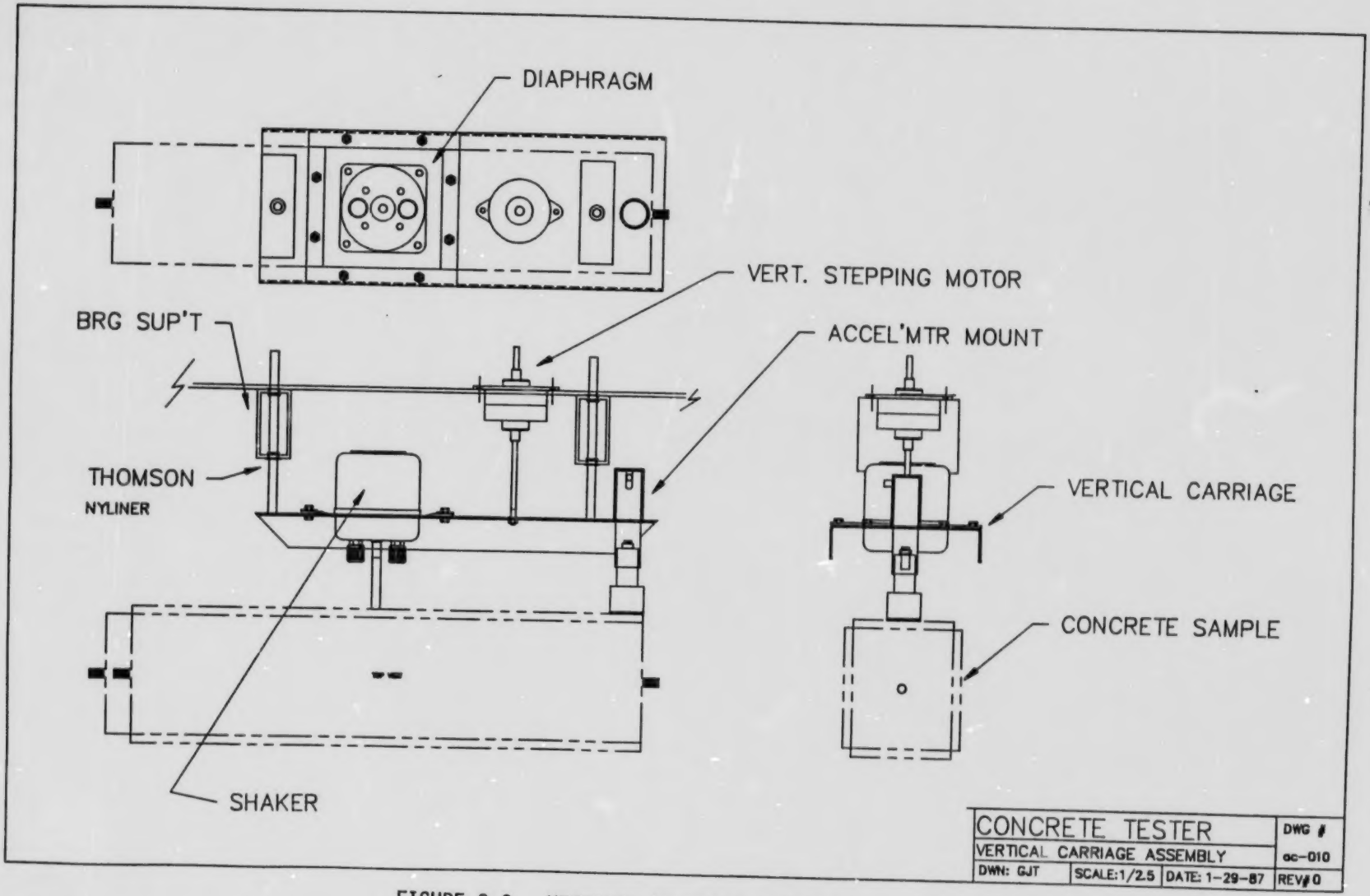



FIGURE 3.3 VERTICAL CARRIAGE ASSEMBLY

## 3.3 Concrete Specimen Support/Water Circulation Systems

ASTM Standard C666-80, procedure A, specifies that the concrete be completely surrounded by water at all times while being subjected to freeze-thaw cycling. When measurements are being conducted the concrete must be supported in air. For these two reasons a watertight containment box with an automated filling and emptying system was designed. Measurement lugs were incorporated in the design such that length measurements could be obtained through a watertight gland.

A detailed design which meets these requirements is shown in Figure 3.4. The containment box is constructed from 16 gauge type 304 stainless steel giving it sufficient strength to withstand the expansion/contraction caused by freezing and thawing of the water within the box.

The concrete is surrounded by approximately 3 mm of water on the sides, top and bottom and approximately 6 mm at each end and is supported on 3 mm dia. rods located at the first mode nodal points. A filling/draining pipe is located in the centre of each box, and is attached to the water piping system. A neoprene diaphragm covers each end of the container through which the measurement lugs pass.

The measurement lug shown in Figure 3.5 consists of a compression ring brazed to a threaded stud and a locknut. The rubber diaphragm which forms the end of the containment box is compressed between the nut and the compression ring to form a watertight seal. Both the measurement lug and locknut are designed to screw onto a 1/4" NC stud cast into the end of each concrete specimen. Use of this stud is standard practice by CANMET. The measurement lug has a polished end to provide a surface to which repeatable and accurate measurements can be made by the LVDT. In addition, the overall length of the concrete specimen and measurement lugs can be adjusted by altering the position of the lug on the stud. This permits an adjustment to be made to suit the measurement caliper, if required.

The water filling system is shown in Figure 3.6. This system is connected to the standard domestic supply by a fitting on the back of the freeze-thaw machine. From this fitting the water is piped through plastic tubing to the filling solenoid valve, the level switch and the containment boxes. The water level in the containment boxes is controlled by a normally closed switch located at the same level as the 'full' water level in the containment boxes. When the water reaches this level the switch opens, which in turn, closes the solenoid valve. The containment boxes are emptied through a second solenoid valve. Both valves are controlled by the electronic control system.

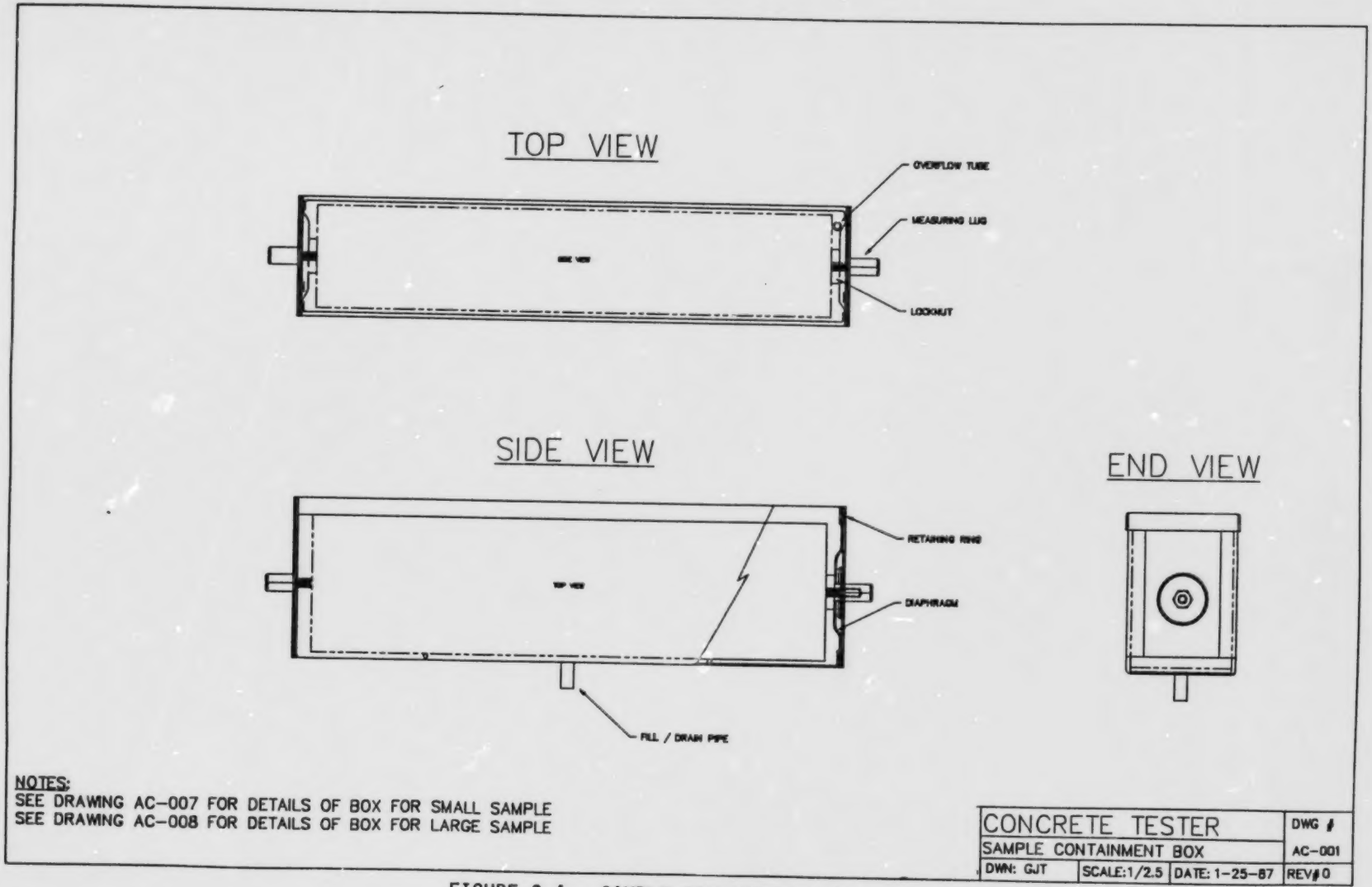



FIGURE 3.4 SAMPLE CONTAINMENT BOX

FIGURE 3.5

VIEW OF MEASUREMENT LUG

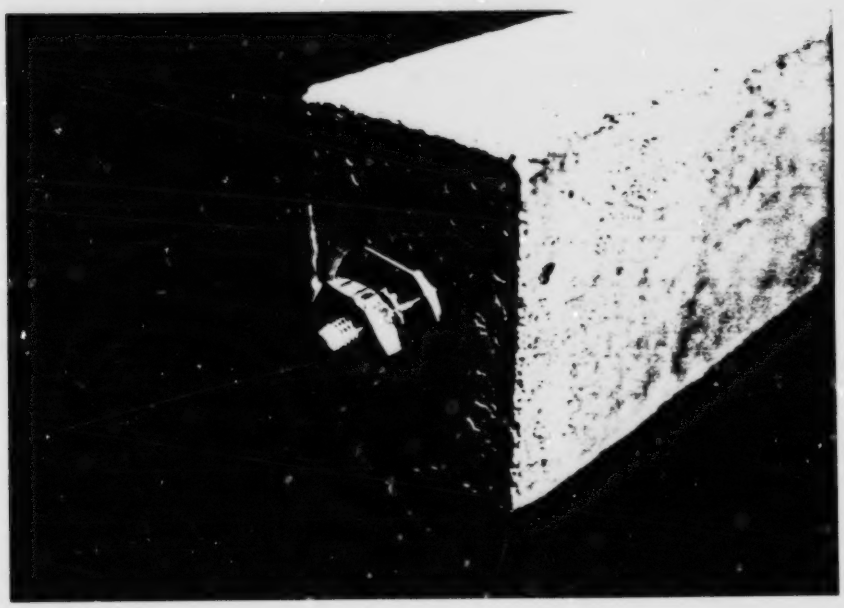
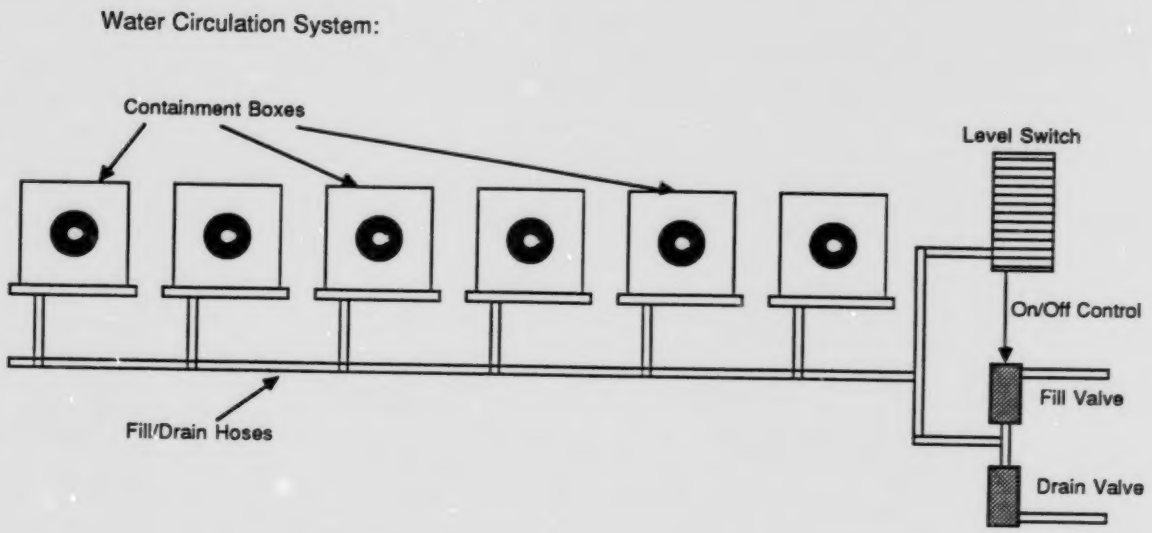


FIGURE 3.6
WATER FILLING SYSTEM



## 3.4 Main Carriage and Internal Frame

In order to use a single set of measuring instruments for six concrete specimens, a carriage was required to position the measuring instruments over each specimen. This main carriage is mounted to a frame within the test chamber by linear bearings and moved between measurement locations by a stepping motor driving an Acme-threaded lead screw.

This system was chosen for reasons of availability, cost and ease of control. Alternative systems such as a cogbelt or chain drive, and DC motors were considered but not found to be satisfactory. The cogbelt was determined to be less accurate and more expensive than the threaded rod while the DC motor required an accurate feedback control system to function correctly. A stepping motor driving a threaded rod appeared to provide the best system to control the linear displacement of the main carriage.

A full track bearing at one end of the carriage provides vertical and lateral support and prevents rotation about any axis. The bearing at the opposite end of the carriage provides vertical support only. This arrangement shown in Figure 3.7 and 3.8 respectively, prevents binding due to misalignment of the two parallel bearings.

In addition to supporting the main carriage, the frame also supports the containment boxes as shown in Figure 3.9. The position of these boxes is set by frame spacers fastened between each box.

## 3.5 Refrigerated Chamber, Electronic Enclosure and Base Design

The refrigerated chamber design was based on the dimensions of the concrete specimens, measuring carriage, and supporting frame which fit inside it. The chamber is constructed from 16 gauge enameled steel with 3 inches of polyurethane foam insulation (see Figure 3.10). Access is provided by a hinged top which also contains a triple panel viewing window.

The refrigerated chamber is mounted to a base frame which also provides support for the refrigeration compressor and the electronics enclosure. The refrigeration compressor requires a supply of air, and in order to accommodate this requirement louvers are provided in the front and side of the electronics enclosure base. The positioning of these louvers permits the freeze-thaw machine to be located against a back wall without affecting the airflow to the compressor.

## 3.6 Electronic Control Systems

The computer control system and electronic support circuitry designed for this freeze-thaw testing machine is described in the following sections.

The control system consists of a desk top computer along with associated peripherals, interface electronics, and signal conditioning for the various sensors and power supplies. Figure 3.11 gives an overview of the basic system components and their inter-connection.

FIGURE 3.7

VIEW OF TRACK BEARING

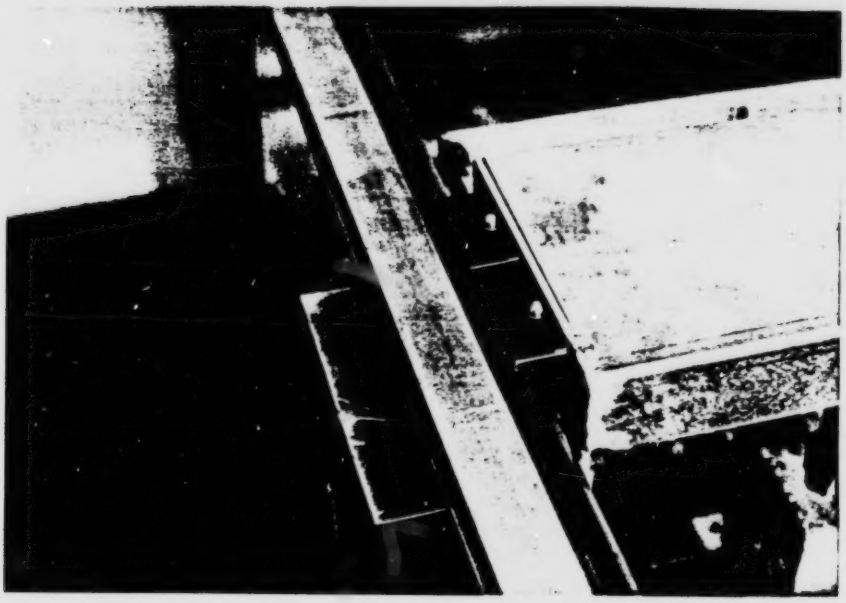
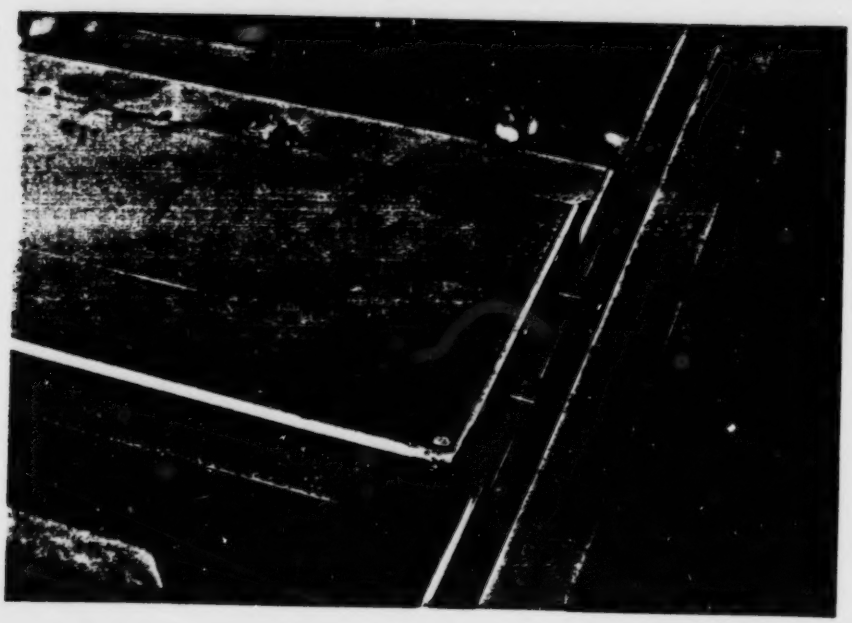


FIGURE 3.8

VIEW OF SUPPORT BEARING



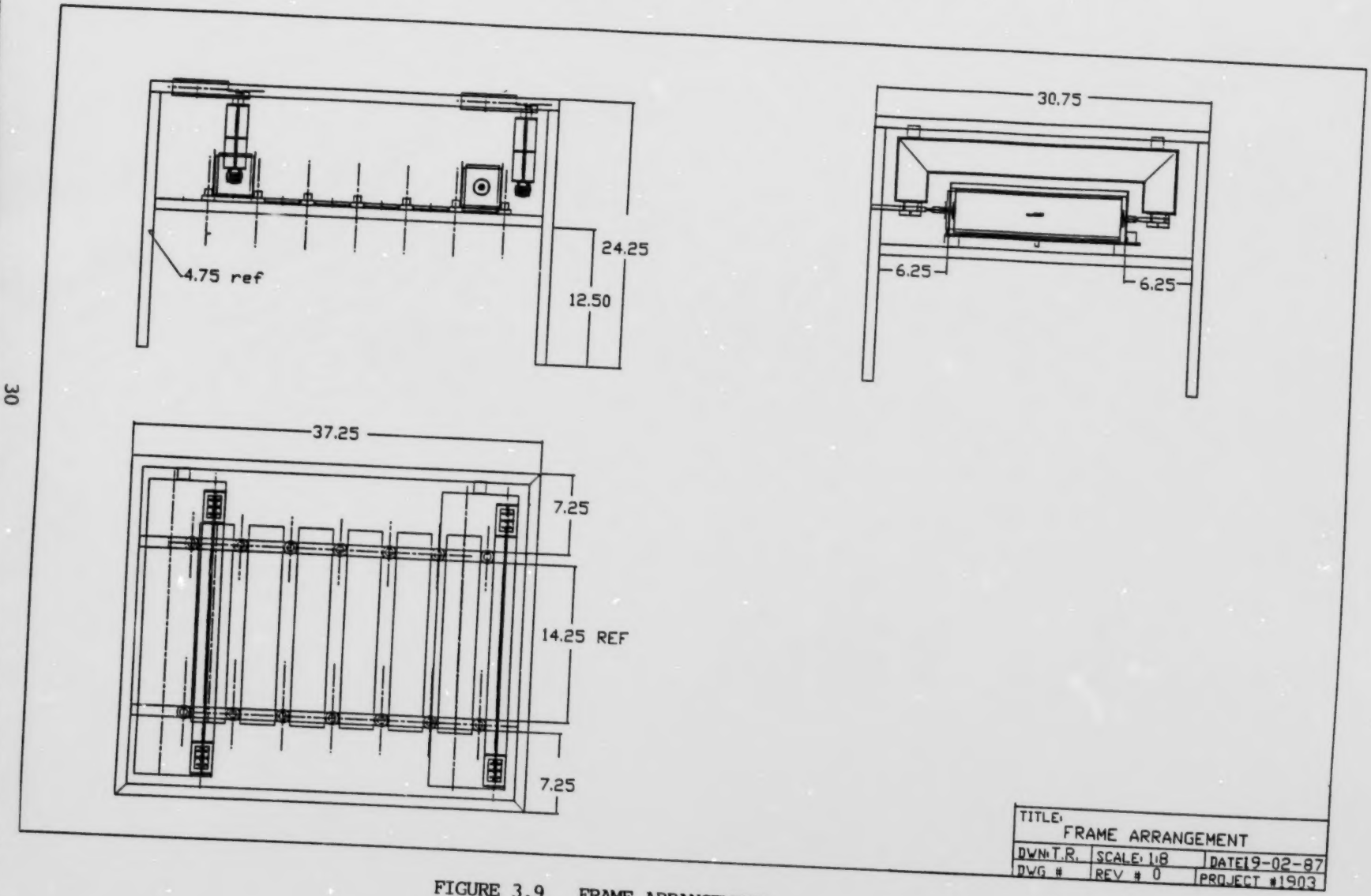



FIGURE 3.9 FRAME ARRANGEMENT

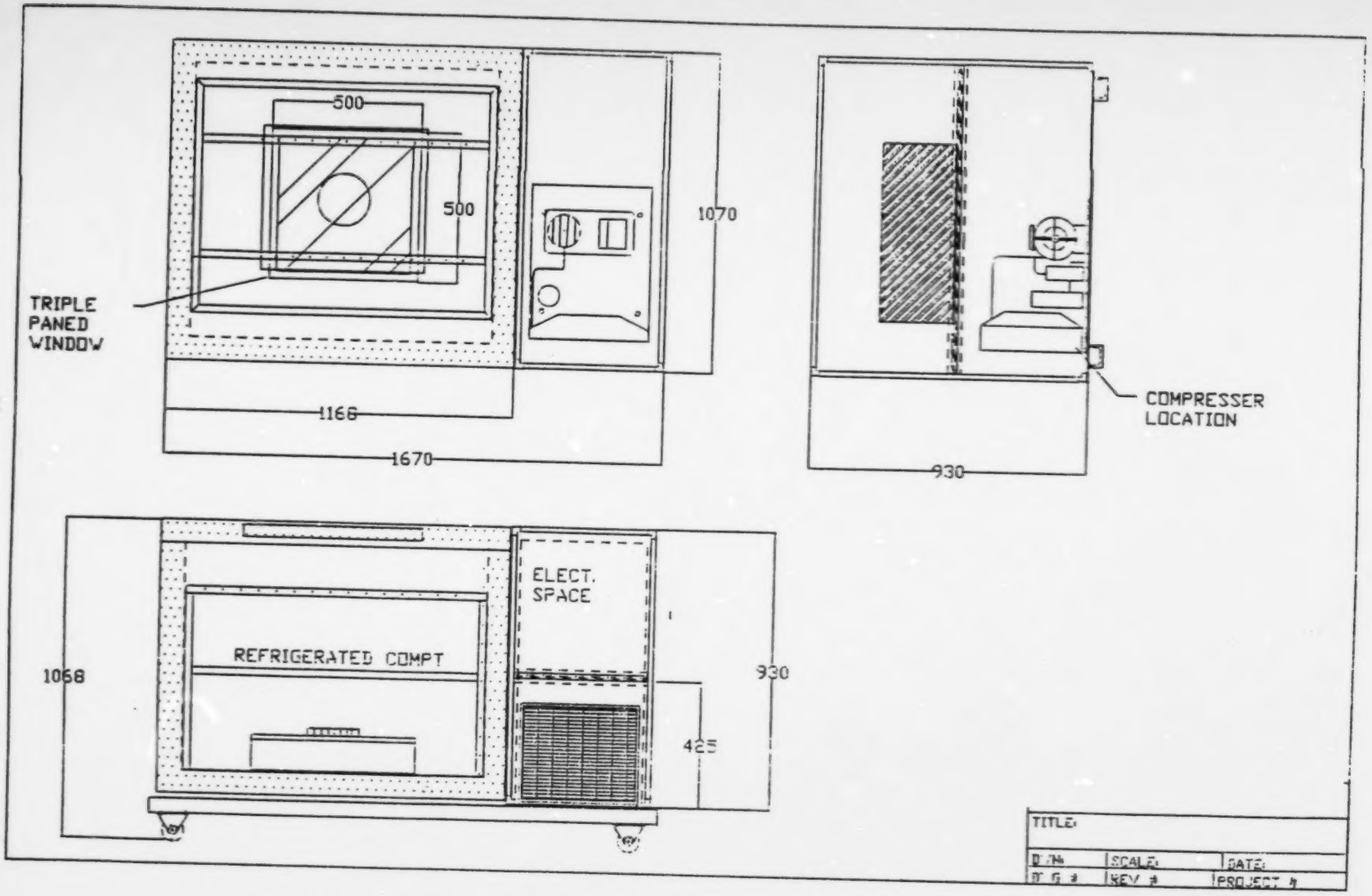
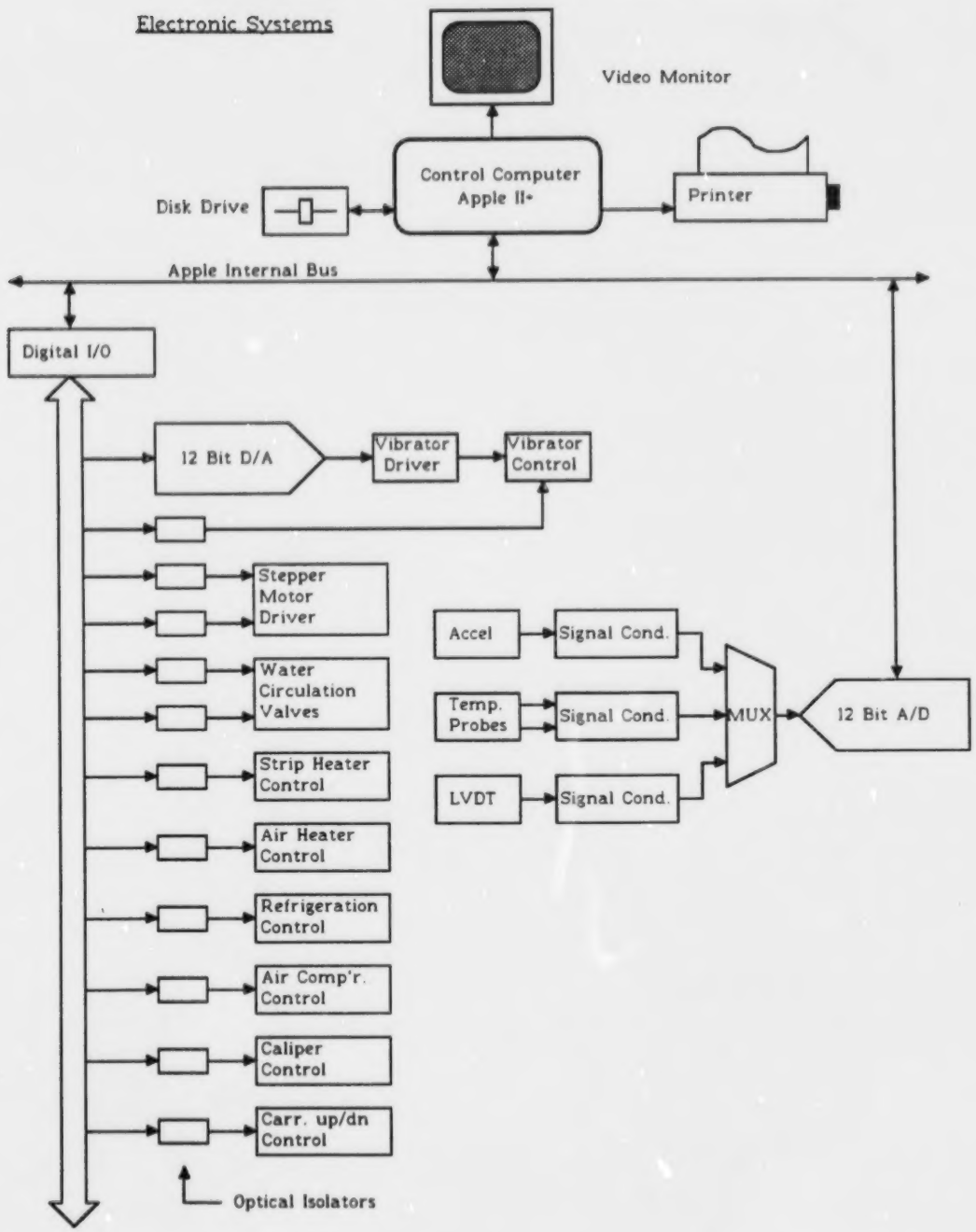



FIGURE 3.10 REFRIGERATION SYSTEM DESIGN

FIGURE 3.11

FREEZE/THAW TESTING MACHINE: ELECTRONIC SYSTEMS



### 3.6.1 Computer

An Apple II personal computer was selected for the main control, data acquisition and processing tasks. It was easily configured with the necessary peripheral devices as well as analog and digital interfaces.

Peripherals include:

- Video display unit: (VDU) displaying system status and prompts for data entry.
- Dot matrix printer which provides hard copy printout of all measurements and calculated parameters for each sample.
- Floppy disk drive for program storage.

In addition, the following interface cards have been installed:

- Disk drive interface card,
- Time-of-day clock card,
- 32 bit digital input/output (I/O) card
- 12-bit, 16 channel analog to digital converter.

The computer functions essentially as a process sequencer. Under program control, it subjects the concrete samples to a set number of thermal cycles, measures the resonant frequency and changes in length of each individual sample, prints the results, and determines the onset of sample failure. This cycle is repeated a number of times chosen by the operator, or until a sample has failed.

In addition to this, the computer provides some monitoring functions, and alerts the operator if any intervention is necessary.

### 3.6.2 Interface Electronics

Although the computer performs all control functions, it does not have the electrical capacity to directly activate high load devices such as the refrigeration system, heaters, or vibration exciter.

Also, since the computer is a digital device, it cannot directly interact with inherently analog devices such as the temperature probes and accelerometers.

For this reason, interface and drive electronics were provided.

In order for the computer to activate or surge certain processes, it must be configured with input/output (I/O) ports. In this application, 32 individually selectable lines were made available for use. These are divided into four 8-bit ports since the computer's internal architecture functions with 8-bit quantities. Table 3.2 describes the function of each line.

As a precaution against any power surges, ground loops, or 'spikes' that may damage the computer, all I/O lines (except A0-A7 and B0-B3) are isolated from their controlled devices by optical isolators.

The isolators specified for this application not only provide circuit protection but contain drivers capable of activating 110 VAC loads. These are sufficient for directly controlling low current devices such as solenoid valves. However, larger loads such as the refrigeration system or air compressor, must be activated by higher capacity, electro-magnetic contactors.

Twelve I/O lines (A0-A7, B0-B3) are used as input to a digital to analog converter (DAC). The binary value output to these lines, is converted to a voltage level which in turn controls the frequency of an oscillator. This signal is amplified and used to drive the vibration exciter. The twelve bit converter can, in this manner, provide a frequency sweep range of 525 Hz to 7370 Hz in 1.67 Hz steps.

Vibrations induced in the concrete samples are sensed by a piezoelectric accelerometer. The accelerometer is connected to its own charge amplifier which, in turn, develops a signal proportional to acceleration. Since the application only requires a relative amplitude of acceleration, the signal is converted to a DC voltage by an RMS to DC converter. As the computer conducts a sweep of frequencies, it measures the level of the DC signal where a relative peak value indicates the frequency at which the sample resonates. Figure 3.12 illustrates this process.

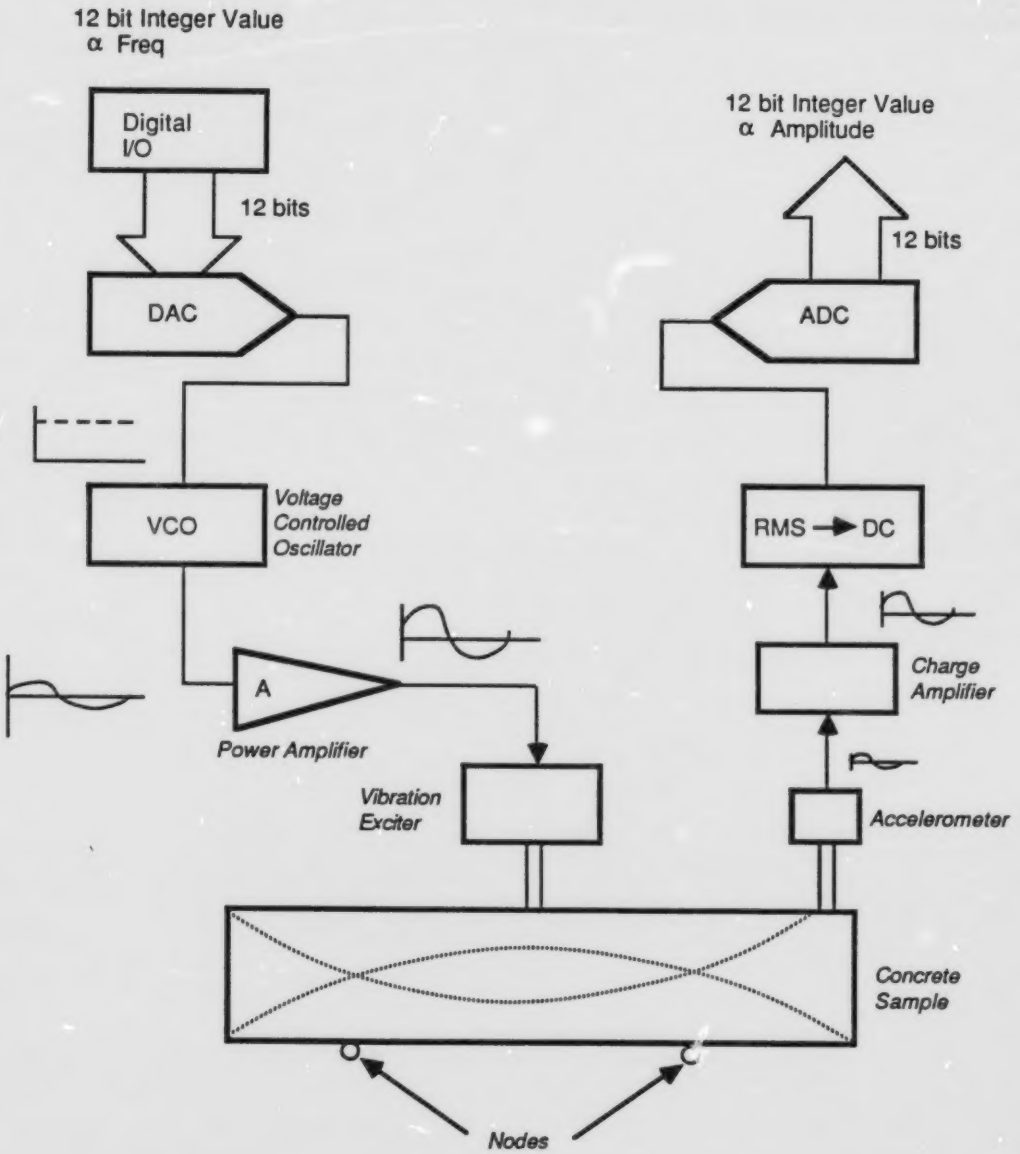
To be read by the computer, the analog signals must first be converted to digital quantities. The analog to digital converter specified for this task can provide 12-bit conversions on any of 16 available analog channels. Of these, two have been designated for temperature probe signals, and a third for amplitude of vibrations.

TABLE 3.2

DIGITAL I/O PORT DESIGNATION

| PORT | BIT | INPUT/OUTPUT | FUNCTION |
|---|---|---|---|
| A | 0 | Output | To 12-bit digital to analog converter |
| | 1 | Output | |
| | 2 | Output | |
| | 3 | Output | |
| | 4 | Output | |
| | 5 | Output | |
| | 6 | Output | |
| | 7 | Output | Controls vibration frequency |
| B | 0 | Output | |
| | 1 | Output | |
| | 2 | Output | |
| | 3 | Output | |
| | 4 | Output | Step motor direction control |
| | 5 | Output | Step motor pulse line |
| | 6 | Output | Water fill control |
| | 7 | Output | Water drain control |
| C | 0 | Output | Instrument platform up/down control |
| | 1 | Output | LVDT control |
| | 2 | Output | Air compressor activation |
| | 3 | Output | Refrigeration activation |
| | 4 | Output | Strip heater activation |
| | 5 | Output | Air heater |
| | 6 | - | Spare |
| | 7 | Output | Vibrator Activation |
| D | 0 | Input | Carriage position sensor |
| | 1 | Input | Instrumentation platform position sensor |
| | 2 | - | Spare |
| | 3 | - | Spare |
| | 4 | - | Spare |
| | 5 | - | Spare |
| | 6 | - | Spare |
| | 7 | - | Spare |

FIGURE 3.12
RESONANT FREQUENCY MEASUREMENT PROCESS



### 3.6.3 Signal Conditioning

Analog devices such as the temperature probes, accelerometers and LVDT probe are specialized instruments needing specific voltage excitation, signal amplification and conversion. This ensures their proper functioning and enables the computer to obtain accurate readings.

The test chamber and concrete core temperatures are sensed by platinum RTD (Resistance Temperature Detector) probes. As their name suggests, the ohmic resistance of the platinum sensing element varies proportionally with temperature. Resistance readings are obtained by measuring the voltage drop across the probe which is supplied with a constant electrical current. Care was taken in the design of the current source, to deliver low level currents (≈ 1 mA) to each probe. Higher currents would have caused self-heating in the probes, and induced inaccuracies in the readings. Figure 3.13 illustrates the basic functioning of the temperature sensing circuits.

The accelerometer used to sense vibrations (Dytran Model No. 3100) has been supplied with its own charge amplifier (Dytran Model No. 4110). It delivers a signal proportional to the instantaneous acceleration at one end of the concrete sample. As was discussed in previous sections, this signal is converted to an easily digitized DC voltage, which is also proportional to acceleration. The circuit designed for this purpose incorporates an RMS (root mean square) to DC converter chip (Analog Devices AD636) as well as an operational amplifier to provide scaling of the signal.

The LVDT probe used for length measurements was also supplied with its own signal conditioning electronics. The only additional circuit requirement is another operational amplifier used for scaling and offset compensation.

### 3.6.4 Power Supply

Electrical power required for interface and signal conditioning electronics is provided from three main power supplies and a voltage regulation and distribution board.

The main power supplies provide +30, -30, and 5 volts DC. Other voltage levels (+15, -15, +12, -12, -5, volts DC) are derived from the main supplies by 3-terminal linear voltage regulators. Table 3.3 shows the power requirements of each interface and signal conditioning circuits.

FIGURE 3.13

**Temperature Probe Signal Conditioning**

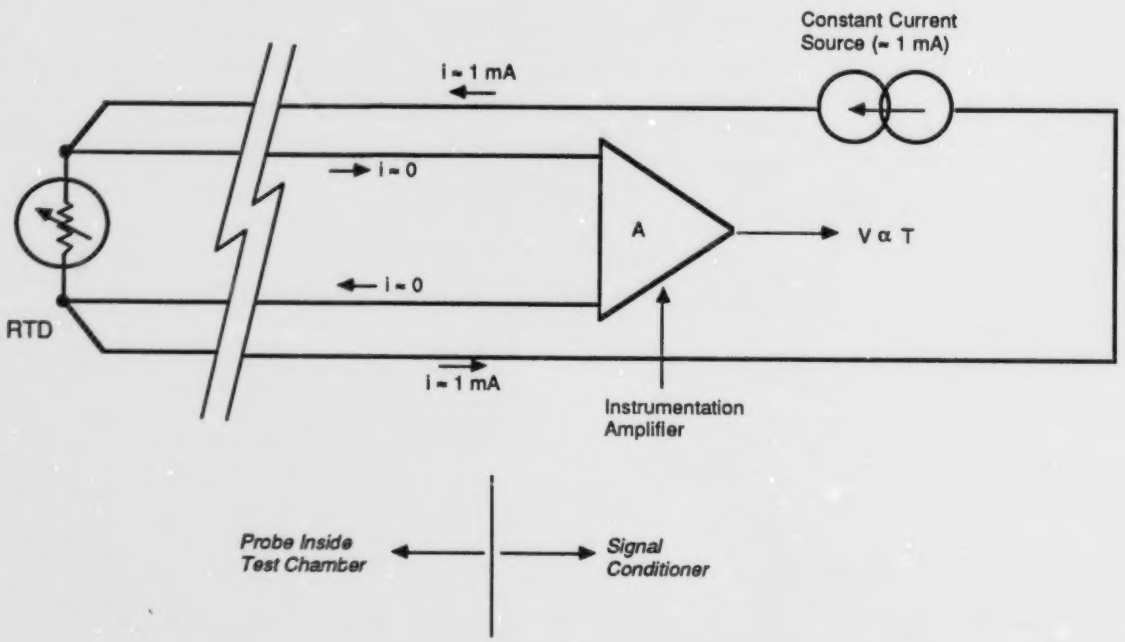


TABLE 3.3

| FUNCTION | REQUIRED SUPPLY |
|---|---|
| Stepper Motor | +5V @ 2.5A, +12V @ 100 mA |
| LVDT Power Supply | 115VAc @ 0.5A |
| Accelerometer Signal Conditioning | ±15V, ±12V, ±5V: @ 100 mA |
| 12 Bit DAC Board | ±12V, ±5V @ 100 mA |
| Analog Signal Conditioning | ±15V, ±5V @ 100 mA |
| Vibrator Amp | ±30V @ 1.5A, ±15V @ 100 mA |

Total Power +5 @ 3.5A -5 @ 200 mA, ±15 @ 200 mA, ±12 @ 300 mA, ±30 @ 1.5A

## 3.7 Software

All software developed for this application was written in Applesoft BASIC on an Apple II computer. Modular coding practices were utilized throughout, in order to provide rapid development and increased reliability.

The routines handling analog to digital conversions, digital input/output and time of day functions, are written in 6502 assembler code, and were supplied as firmware by the manufacturers of each interface board, respectively.

The following pseudo-code serves to give the reader an understanding of the program flow.

```
PROGRAM Freeze/Thaw;

BEGIN
        Initialize_IO_ports;
        Initialize_Variables;
        Park_Carriage
        Get_Time;
        INPUT("Is time okay?"); Answer
        IF Answer = "NO" THEN Load_and_Run (clock set);
        Get_Operating_Parameters;
        No_of_Measurement_cycles = Total_F/T_Cycles DIV No_Cycles_Between_Meas;
        No_of_Leftover_F/T_cycles = Total_F/T_Cycles MOD No_Cycles_Between_Meas;
        Print_heading;
        Adjust_temperature;
        Take_measurements;
        Original_Lengths: = Lengths;
        Original_Frequencies: = Frequencies;
        FOR Cycle = 1 to No_of_Measurements_Cycles DO
        BEGIN
                Fill_tanks_with_water;
                FOR Freeze_no = 1 to No_cycles_between_meas DO
                BEGIN
                        Freeze_and_thaw;
                END;
                Empty_tanks;
                Adjust_temperature;
                Take_measurements;
                Calculate_parameters;
                Check_for_sample_failure;
                Print_results;

                IF Any_sample_has_failed THEN Print_sample_fail_message;

        END; {cycle}

        IF No_of_Leftover_F/T_cycles ≠ 0 THEN DO
        BEGIN
                Fill_tanks_with_water;
                For Freeze_no = 1 to No_of_Leftover_F/T_Cycles DO
                BEGIN
                        Freeze_and_Thaw;
                END;
                Empty_tanks;
                Adjust_temperature;
                Take_measurements;
                Calculate_parameters;
                Check_for_sample_failure;
                Print_results;
                IF Any_sample_has_failed THEN Print_sample_fail-message;
        END; {leftover F/T cycles}
        Print_test_end_message;
END. {program}
```

```
PROCEDURE Get_operating-parameters;

BEGIN
REPEAT
BEGIN;
       INPUT("Enter test name and no.")Test_Name;
       INPUT("Enter total no. of freeze/thaw cycles")Total_F/T_Cycles;
       INPUT("Enter no. of cycles between meas.)"No_Cycles_Between_Meas;
       INPUT("Enter no. of samples to be meas.)"No_of_Samples;
       PRINT("Test name:", Test_Name);
       PRINT("Total freeze/thaw cycles:", Total_F/T_Cycles)"
       PRINT("No. of cycles between measurements:", No_Cycles_Between_Meas);
       PRINT("No. of samples to be measured:", No_of_Samples);
       INPUT("Is this information correct?"), Answer;
END
UNTIL Answer = "Yes";
END; {procedure}


PROCEDURE Take_measurements;

BEGIN

       Park_carriage;
       For Block = 1 to No_of_Samples DO
       BEGIN
              Move_carriage_to_length_meas_pos (Block);
              Adjust_temperature;
              Turn_on_compressor;
              Extend_LVDT;
              Take_length_meas.;
              Retract_LVDT;
              Turn_off_compressor;
              Move_carriage_to_freq_meas_pos (Block);
              Adjust_temperature;
              Turn_on_compressor;
              Lower_vibration_instruments;
              Find_resonant_frequency;
              Raise_vibration_instruments;
              Turn_off_compressor;

       END;

       Park_carriage;

END; {Procedure}
```

```
PROCEDURE Freeze_and_thaw

BEGIN

        Target_Low: = -17.8; {Deg C}
        Target_High: = +4.4;

        {Freeze}

        REPEAT
        BEGIN
                Take_temperatures;
                IF Air_Temp > Target_Low-18 THEN Turn_on_refrig;
                IF Air_Temp < Target_Low-22 THEN Turn_off_refrig;
        END;
        UNTIL Core_Temp < = Target_Low;

        {Thaw}

        Turn_on_both_heaters;
        REPEAT
        BEGIN
                Take_temperatures;
                IF Air_Temp < Target_High +3 THEN Turn_on_both_heaters;
                IF Air_Temp > Target_High +7 THEN Turn_on_concrete_htrs_only;
        END;
        UNTIL Core_Temp > = Target_High;

END; {Procedure}
```

```
PROCEDURE Find_Resonant_Frequency;

BEGIN

        Turn_on_vibrator;
        Max_Amplitude: = 0;
        For Freq = Low_Freq TO High_Freq STEP 4 DO
        BEGIN
                Set_vibration_freq (Freq);
                Measure_amplitude;
                IF Amplitude > Max_Amplitude THEN DO
                BEGIN
                        Res_Freq:= Freq;
                        Max_Amplitude:= Amplitude;
                END;
        END;

        Max_Amplitude:= 0;
        For Freq = Res_Freq-100 TO Res_Freq + 100 STEP 1 DO
        BEGIN
                Set_Vibration_freq (Freq);
                Measure_Amplitude;
                If Amplitude > Max_Amplitude THEN DO
                BEGIN
                        Res_Freq:= Freq;
                        Max_Amplitude:= Amplitude;
                END;
        END;
        Frequency (Block):= Res_Freq;

END; {Procedure}
```

```
PROCEDURE Calculate_Parameters;

BEGIN

        FOR Block:= 1 to No_of_Samples DO
        BEGIN
                Rel_Dynamic_Mod_of_Elasticity(Block):= Frequency (Block)
                 ^2/Original_Frequency(Block)^2 * 100;
                Change_in_Length(Block):= (Length(Block)-Original_Length(Block)/
                 Original_Length(Block) * 100;
                Durability_Factor(Block):= Rel_Dynamic_Mod_of_Elasticity(Block)*
                 Current_no_of_F/T_Cycles  /    Total_F/T_cycles;
        END;

END;



PROCEDURE Check_for_sample_failure;

BEGIN
        FOR BLOCK:= 1 to No_of_samples DO
        BEGIN

                IF Rel_Dynamic_Mod_of_Elasticity(Block) < 60 OR
                 Change_in_Length_(Block)>0.1 THEN Sample_Fail(Block):=
                 TRUE;

                IF Sample_Fail(Block) THEN Any_Sample_has_failed:= TRUE;
        END;
END;
```

## 3.8 Modifications Required to Freeze-Thaw Machine During Construction and Preliminary Testing

1. 1/4" Bore air cylinder driving the length measurement caliper was found to be too small and was replaced by a 9/16" bore model.

2) Stepper Motor used to raise the vertical carriage was unable to develop sufficient force to raise this carriage. As a result it was necessary to replace the stepper motor used to drive this carriage with a double acting pneumatic cylinder and spring arrangement. Two springs were used to return the carriage to its upper position.

## 4. PROTOTYPE TESTING

A series of tests were carried out during the assembly of the freeze-thaw machine to ensure that all individual parts and assemblies functioned correctly by themselves, before they were assembled into the machine. In addition, the performance of the completed prototype was tested to ensure that the temperature cycle met the ASTM specification, and that the measurements were performed reliably.

### 4.1 Sub Assembly Testing Procedure

During sub assembly testing the operation of the assemblies listed in Table 4.1 was verified.

Length Measuring Caliper

The LVDT was installed in the length measuring caliper and was calibrated through its signal conditioning electronics and the A-D converter to directly obtain the conversion factor required for this measurement. In addition, the LVDT power supply, signal conditioning and A-D circuits were individually calibrated to determine any gain or offset produced. The repeatability of the length caliper was checked by making 100 consecutive measurements of the length of a concrete specimen. This specimen was placed in a containment box and end lugs were attached to completely simulate testing conditions for this instrument.

Vibration Measuring Carriage

A simultaneous calibration of the accelerometers and vibration exciter was carried out to ensure that the frequency input into the vibration exciter was identical to that recorded by the accelerometer. These signals were compared using a dual trace oscilloscope on which both the vibration exciter input signal and the accelerometer output signal could be viewed.

The ability of the vibration measuring carriage to determine the resonance frequency of the concrete was determined by using an oscilloscope in a similar arrangement to that described above. While viewing the input and output signals on the oscilloscope, the frequency was stepped through the range of 800 Hz to 7000 Hz. The amplitude of the output signal was observed to increase dramatically as resonance was reached, then return to near zero when the frequency was increased.

The amplitude of the accelerometer output signal is converted to a voltage level by an RMS amplitude to DC converter. The operation and calibration of these circuits was determined by using input signals of known frequency and amplitude and measuring the response.

The final test performed on the vibration measuring assembly was to determine the resonant frequency of a concrete sample located within its containment box and mounted on the test frame. This test was repeated 100 times and the measured results compared with measurements obtained for the same sample from an independent source. This test was conducted with satisfactory results, and the assembly was then incorporated into the machine.

TABLE 4.1

SUB-ASSEMBLIES AND COMPONENT PARTS

SUBJECTED TO TESTING

a) Length Measuring Caliper

- LVDT
- Air Cylinder and Solenoid Valve
- Signal Conditioning and A-D Conversion

b) Vibration Measurement Carriage

- Vibration Exciter
- Accelerometer
- Air Cylinder and Solenoid Valve
- RMS-DC Converter

c) Main Carriage

- Stepping Motor

d) Water Filling Systems

- Solenoid Valves
- Level Switch

e) Refrigeration System

- Temperature Probes
- Strip Heaters
- Air Heater

Main Carriage

A positioning and repeatability test was conducted in order to measure any cumulative inaccuracies in the main carriage drive system. Under program control, the carriage was repeatedly driven from one extreme of its travel to the other. After a large number of cycles had been executed, no positioning error could be measured.

Another test was performed to determine the effect that relatively large positioning errors had on length and frequency measurements. A number of measurements for each parameter was recorded at the optimal carriage position and then again at approximately 2 mm to either side of this position. No significant discrepancies were recorded.

Refrigeration/Heating System

The ability of the refrigeration and heating system to subject six concrete samples to the required thermal cycle, while maintaining a homogeneous temperature gradient in all samples was required.

For this purpose, six thermocouples were cast into each of two concrete specimens. The location of each thermocouple is shown in Figure 4.1. The specimens, in turn, were installed in the center and end positions of the freeze-thaw machine. The signal from each thermocouple was monitored with the use of a rotary switch and a thermocouple temperature indicator.

As the temperature was cycled between +4.4°C and -17.8°C, it was observed that temperature differences between samples were of approximately 2°C and that temperature gradients within each sample were within acceptable limits.

Water Filling System

The operation of the water filling/emptying was tested to determine the correct position of the level switch. This was accomplished by moving the switch vertically in its mount until a water level approximately 3 mm above the concrete top surface was obtained.

## 4.3 Operational Testing of Assembled Machine

This test was designed to verify the proper operation of the completed freeze-thaw testing machine. To successfully complete the trial program, it had to subject a number of concrete samples to either forty complete cycles, or one week of testing, without significant malfunction.

A special set of concrete samples, designed to fail at some point during the forty-cycle trial, were cast by CANMET technicians. These are to be subjected to freeze-thaw testing using conventional methods as well as the automated test machine. A comparison of results obtained by both methods will verify the machine's proper functioning.

## 5. CONCLUSIONS

One complete and functional prototype freeze-thaw testing machine was delivered to the CANMET laboratories. The design and construction of this prototype machine, capable of meeting the exacting standards set by ASTM C666, proved to be an ambitious task given original budget estimates.

The wide range of different technologies which had to be integrated into one machine made it necessary to draw on the experience of many experts in the following fields:

- HVAC engineering
- Mechanical design
- Finite analysis analysis
- Control system design
- Instrumentation systems
- Analog circuit design
- Digital system design
- Software design
- Program coding
- Prototype construction

The level of complexity within this machine can readily be compared with that of a complete robotics system.

Much experience has been gained during all phases of this project. From this it was observed that original cost estimates were not accurate and that certain tasks such as design and construction of the refrigeration chamber and associated systems could possibly have been omitted.

## 6.0 RECOMMENDATIONS

With the experience gained during the design and construction of a freeze-thaw testing machine, the following recommendations can be made:

1. A commercially available test chamber of reduced dimensions could have been acquired from commercial sources.

2. A refrigeration system of increased capacity should be specified.

3. An investigation into the use of multiple transducers instead of a single set mounted on a movable carriage, should be undertaken. The extra cost for a movable instrument carriage along with all supporting hardware and software, may well equal the increased expense of multiple transducers. A system with fewer moving parts exposed to a harsh environment would improve overall reliability.

4. It should be possible to exchange both the vibration and length measurement sensors for a single unit capable of sensing both parameters. A non-contacting proximity probe or an LVDT could be used, but only if the vibrations are induced in the longitudinal direction.

5. If a movable carriage arrangement is to be designed, then a more precise arrangement for positioning the vibration exciter should be considered. If this transducer does not properly contact the specimen, it can either provide poor quality results or even damage itself.

6. A more modern computer could be specified along with a better development language as this would assure reduced development times.

7. A particle trap should be installed in order to prevent any concrete sediments from clogging the water circulation lines.

## 7. ESTIMATED COST OF THE TEST APPARATUS FOR FUTURE PRODUCTION

The costs associated with the production of another testing machine are outlined in Table 7.1. It should be noted that these costs are for an almost identical unit, the only exceptions would be slight changes in layout and configuration of some instrumentation as well as the mechanism used to raise and lower the vibration instruments. It is estimated that manpower requirements for production of a second testing machine are approximately 1000 man-hours.

Costs have also been calculated (Table 7.2) for production of a modified machine incorporating most points outlined in the recommendation section (6). The difference between both costs is small but the higher reliability of a new design would make it more attractive.

TABLE 7.1

ESTIMATED COSTS FOR PRODUCTION OF SECOND FREEZE-THAW TESTING MACHINE

Materials

| Item No. | Description | Cost / Item | Qty | Cost |
|---|---|---|---|---|
| 1 | Test Chamber | $4,500 | 1 | $4,500 |
| 2 | Cooling System | $1,000 | 1 | $1,000 |
| 3 | Heaters | $100 | 6 | $600 |
| 4 | Computer | $1,500 | 1 | $1,500 |
| 5 | Peripherals | $800 | 1 | $800 |
| 6 | Interface Cards | $2,000 | 1 | $2,000 |
| 7 | Signal Conditioning | $2,000 | 1 | $2,000 |
| 8 | Vibrations Exciter | $700 | 1 | $700 |
| 9 | Accelerometers | $1,000 | 1 | $1,000 |
| 10 | Temperature Probes | $50 | 2 | $100 |
| 11 | LVDT | $2,000 | 1 | $2,000 |
| 12 | Step Motor & Driver | $500 | 1 | $500 |
| 13 | Carriage & Mechanisms | $2,000 | 1 | $2,000 |
| 14 | Containement Boxes | $100 | 6 | $600 |
| 15 | Water Circ. System | $250 | 1 | $250 |
| 16 | Internal Frame | $2,500 | 1 | $2,500 |
| 17 | Electronics Enclosure | $500 | 1 | $500 |
| 18 | Miscellaneous Items | $500 | 1 | $500 |
| | **Total Materials** | | | **$23,050** |

TABLE 7.2

Estimated Costs for Production of a Modified Freeze/Thaw Testing Machine

**Materials**

| Item No. | Description | Cost / Item | Qty | Cost |
|---|---|---|---|---|
| 1 | Chamber+Cooling Sys | $3,000 | 1 | $3,000 |
| 2 | Heaters | $100 | 6 | $600 |
| 3 | Computer | $2,000 | 1 | $2,000 |
| 4 | Peripherals | $800 | 1 | $800 |
| 5 | Interface Cards | $1,000 | 1 | $1,000 |
| 6 | Signal Conditioning | $2,000 | 1 | $2,000 |
| 7 | Vibrations Exciter | $700 | 6 | $4,200 |
| 8 | Temperature Probes | $50 | 2 | $100 |
| 9 | Prox Detectors | $1,000 | 6 | $6,000 |
| 10 | Containement Boxes | $100 | 6 | $600 |
| 11 | Water Circ. System | $250 | 1 | $250 |
| 12 | Internal Frame | $1,000 | 1 | $1,000 |
| 13 | Electronics Enclosure | $500 | 1 | $500 |
| 14 | Miscellaneous Items | $500 | 1 | $500 |
| | **Total Materials** | | | **$22,550** |

# APPENDIX A

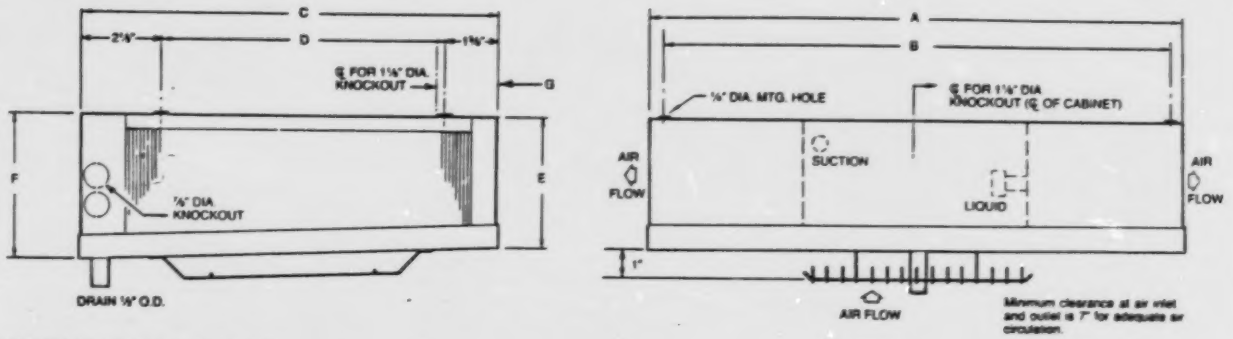
## FREEZE-THAW MACHINE

## COMPONENT SPECIFICATIONS

# TWO-WAY UNIT COOLERS

## HIGH TEMPERATURE MODELS FOR APPLICATIONS ABOVE 2°C (35°F)
## ELECTRIC DEFROST MODELS FOR APPLICATIONS 2°C (35°F) OR BELOW

## DIMENSIONS AND SPECIFICATIONS




## DIMENSIONAL DATA

| DIMENSIONS | A | B | C | D | E | F | G | LIQ. | SUCT. |
|---|---|---|---|---|---|---|---|---|---|
| TW87 (ED) TW126 (ED) | 18 9/16 | 17 3/4 | 13 7/8 | 9 3/4 | 4 9/16 | 4 3/4 | 2 | ½ FL | ⅜ OD |
| TW166 (ED) TW203 (ED) | 18 9/16 | 17 3/4 | 13 7/8 | 9 3/4 | 5 9/16 | 5 3/4 | 2 | ½ FL | ⅜ OD |
| TW250 (ED) TW300 (ED) | 21 9/16 | 20 3/4 | 18 7/8 | 14 3/4 | 5 9/16 | 5 3/4 | 2 | ½ FL | ⅜ OD |

## APPLICATION DATA

| MODEL | *BTUH CAPACITY | | HEATER DEFROST WATTS | CFM | MOTOR H.P. (115/1/60) | REFRIGERANT †CHARGE | SHIPPING WEIGHT |
|---|---|---|---|---|---|---|---|
| | per 0.55°C (1°F) TD | @ 5.5°C (10°F) TD | | | | | |
| TW 87 (ED) | 87 | 870 | 410 | 130 | 1/25 | 0.50 | 15 lbs. |
| TW126 (ED) | 126 | 1260 | 410 | 180 | 1/25 | 0.75 | 16 lbs. |
| TW166 (ED) | 166 | 1660 | 410 | 237 | 1/25 | 1.00 | 18 lbs. |
| TW203 (ED) | 203 | 2030 | 410 | 270 | 1/25 | 1.25 | 19 lbs. |
| TW250 (ED) | 250 | 2500 | 505 | 440 | 1/25 | 1.5 | 25 lbs. |
| TW300 (ED) | 300 | 3000 | 505 | 440 | 1/25 | 1.8 | 26 lbs. |

*Severity of coil frosting should be considered where selecting low temperature unit coolers. For operation in severe frosting conditions, multiply unit ratings by 0.85 factor.

†R-12 & R-22 at −17.7° (0°F) SST; R-502 at −28.8°C (−20°F SST with coil 30% full.

**CABINET**
Heavy gauge, white epoxy painted steel used for all cabinet parts. Fan and motor assembly is rigidly mounted to top panel. Drain pan is sloped to provide positive drainage of condensate. Fan guard is vinyl coated steel wire. Plated and non-ferrous fasteners used throughout construction of unit cooler.

**MOTORS and FANS**
Motors are 115/1/60 and are C.S.A. and U.L. approved. Built in thermal overload protection with automatic reset affords motor protection. Permanently lubricated. Thermal terminal block provided for electrical connections.

Five bladed, aluminum fans are statically balanced and individually gauged for contour and alignment.

**COIL**
Dual refrigeration coils afford two way air flow for improved distribution and lowered discharge velocity.

Copper tubes expanded into rippled aluminum fins for maximum heat transfer capacity. Full depth aluminum collars provide accurate control of fin spacing and cover the copper tubing with protective aluminum sheath. KeepRite ripple plate fin and staggered tube construction for optimum heat transfer.

**DEFROST HEATER**
Incalloy sheathed heating element clipped to coil face above drain pan. Factory wired to terminal block.

**DEFROST CONTROLS**
To be supplied by others.

**C.S.A. APPROVAL**
Units are listed by the Canadian Standards Association and shall carry the C.S.A. approval label. Approved for 115/1/60 entering electrical service.

Distributed by

KeepRite

KeepRite Inc.
Subsidiary of Inter-City Gas Corporation
44 Elgin Street, P.O. Box 460,
Brantford, Ont., Canada N3T 5P4

Sales Offices: Halifax, Montreal, Ottawa, Toronto, Burlington, London, Winnipeg, Calgary, Edmonton, Vancouver

MADE IN CANADA

*Due to KeepRite's policy of continuous product improvement, the manufacturer reserves the right to make changes without notice.*

Printed in Canada

DATE: 1/18/85

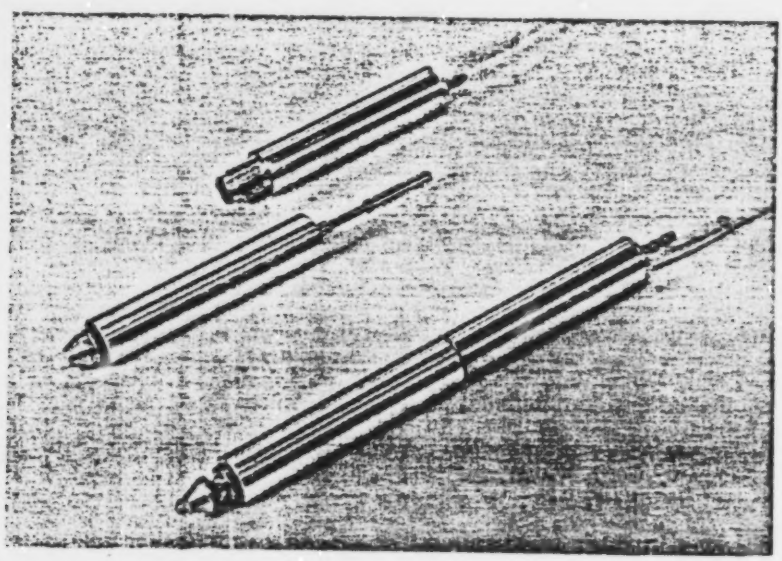
# Preliminary Specifications

## MODEL LBB-375-PA-100A AC TO AC VERSION AIR-EXTEND/ SPRING-RETRACT LINEAR BALL BEARING GAGE HEAD NOW AVAILABLE

Schaevitz' Model LBB-375-PA-100A is a special AC to AC precision gage head that combines air-extend/automatic-spring retract probe operation with a linear ball bearing probe assembly. This compact device features 2-piece, screw-together construction that enables replacement of only part of a unit if partial damage occurs. This can save the user considerable repair time and up to fifty percent of the replacement cost for 1-piece units.

This unit can be used to measure a variety of parts including automotive pistons, valves, shaft journals, etc. It is also highly suitable for many other gaging applications, especially where small size is a factor. The gage head utilizes a linear ball bearing probe assembly that minimizes probe friction and eliminates radial play, thus reducing probe wear and providing excellent repeatability — 4 millionths of an inch. The gage head probe is extended by a piston that operates on dry, oil-free, low-pressure air and when the air pressure is turned off after measurement, an internal spring automatically retracts the probe. In gaging applications, this feature eliminates the need for slides. Vacuum service is unnecessary.

The unit effectively replaces the Schaevitz PCA 240-100 at a more economical cost and uses the same LVDT as the Schaevitz 240-100 and 220-100, thus making it fully compatible with systems using these other types of gage heads. Furthermore, the LBB-375-PA-100A is a conventional unit which is compatible with all Schaevitz signal conditioners.



schaevitz

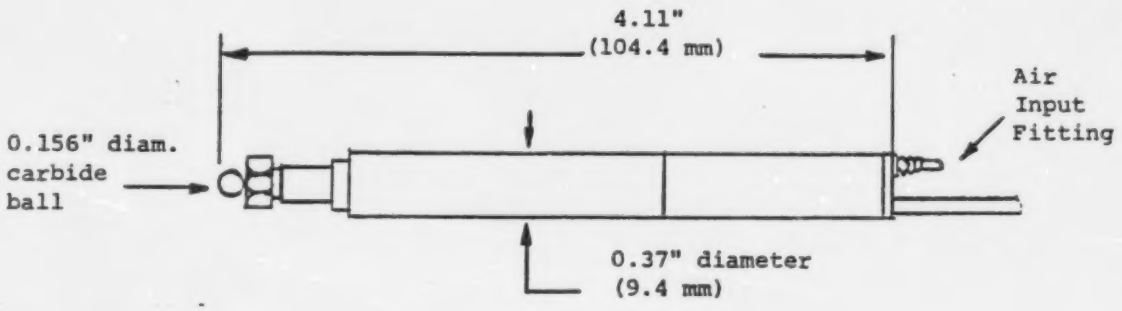
U.S. Route 130 & Union Avenue
Pennsauken, NJ 08110
Tel: (609) 662-8000

543 Ipswich Road
Slough, Berks SL1 4EG England
Tel: (0753) 37622

Centre Art de Vivre, R.N. 13
78630 Orgeval, France
Tel: 3-975-8040

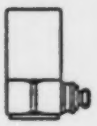
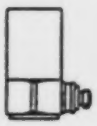
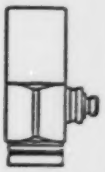
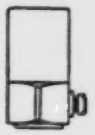
## LBB-375-PA-100A SPECIFICATIONS

| | |
|---|---|
| Bearing System | Linear ball bearing |
| Linear Range | ±0.100 inch (±2.5mm) |
| Total Mechanical Travel | 0.305 inch (7.75 mm), min. |
| Pretravel | 0.025 inch (0.635 mm) |
| Repeatability | 0.000004 inch (0.1 μ m) at constant temp. |
| Linearity | 0.2% of full range output at constant temp. |
| Excitation (See Note 1) | 3.5 V AC rms, 2.5 kHz |
| Sensitivity | 2 mV/.001"/Volt input |
| Electrical Termination | various electrical terminations can be user specified |
| Cable Length | 6.0 feet (1.8 meters) |
| Probe Contact Tip | 0.156" diam. carbide ball, 4-48 UNF-2A thread |
| Recommended Air Supply | Dry, oil-free air filtered through 10-micron filter, 10 psig max. pressure |



DYTRAN INSTRUMENTS INC.

# Quartz Low Impedance Voltage Mode Accelerometers

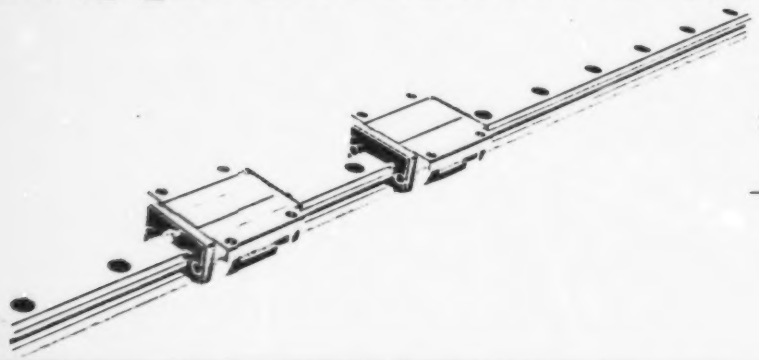
| | 3100A | 3100A24 | 3100A7 | 3125A | 3126A | 312 |
|---|---|---|---|---|---|---|
| |  |  |  |  | | |
| | General Purpose | Seismic | Ground Isolation | Modal | Modal | Moda |
| Weight (Grams) | 57 | 48 | 66 | 40 | 56 | 60 |
| Sensitivity (mV/g) | 100(+/-2%) | 1000(+/-5%) | 100(+/-2%) | 50(+/-2%) | 100(+/-2%) | 100(- |
| Full Scale Range for +/-5 V Output (g's) | 50 | 5 | 50 | 100 | 50 | 50 |
| Frequency Range (Hz) +/-5% | 1-3500 | 2-1000 | 1-3500 | 1-3000 | 1-3000 | 1-300 |
| Frequency Range (Hz) +/-3dB | .33-8000 | 1-1500 | .33-6000 | .5-5000 | .5-5000 | .5-500 |
| Mounted Resonant Frequency (kHz) | 20 | 22 | 20 | 20 | 20 | 20 |
| Electrical Noise (Equivalent g's RMS) | .0007 | .0007 | .0007 | .0007 | .0007 | .000 |
| Base Strain Sensitivity @250 μ Strain (g's/ μ strain) | .012 | .012 | .01 | .008 | .008 | .02 |
| Maximum Vibration (g's) | +/-600 | +/-100 | +/-600 | +/-500 | +/-500 | +/-50 |
| Maximum Shock (g's peak) | 3000 | 200 | 3000 | 1000 | 1000 | 100 |
| Temperature Range (°F) | -60 to +250 | -60 to +250 | -60 to +250 | -60 to +250 | -60 to +250 | -60 to |
| Thermal Coefficient of Sensitivity | .03%/°F | .03%/°F | .03%/°F | .03%/°F | .03%/°F | .03% |
| Discharge Time Constant (Sec) | 1.00 | .40 | 1.00 | 1.00 | 1.00 | 1.0 |
| Connector | 10-32 coaxial | 10-32 coaxial | 10-32 coaxial | 10-32 coaxial | 10-32 coaxial | 10-32 co |
| Seal | Epoxy | Welded/Epoxy | Epoxy | Epoxy | Epoxy | Epox |
| Case Material | 303 S.S. | Stainless Steel | 303 S.S. | 303 S.S. | 303 S.S. | 303 S. |
| Mounting Used During Factory Calibration | Removable 10-32 stud | Removable 10-32 stud | Removable 10-32 stud | Adhesive | Adhesive | Remova 10-32 s |
| Size, Hex X Height (Inches) | 5/8 X 1.1 | .62 X 1.09 | 5/8 X 1.5 | 5/8 X .88 | 5.8 X 1.13 | 5/8 1.1 |
| Recommended Cable Series | 6010A, 6011A | 6010A | 6010A, 6011A | 6010A, 6011A | 6010A, 6011A | 6010A, |
| Electrical Isolation | No | No | Yes | No | No | No |
| Supplied Accessories | Model 6600 mtg stud | Model 6600 mtg stud | Model 6600 mtg stud | ------- | ------- | ------ |
| Available Options: See price list for brief description | 3100A1, 3100A2, 3100A5, 3100A22 | ------- | 3100A8 | ------- | ------- | ------ |

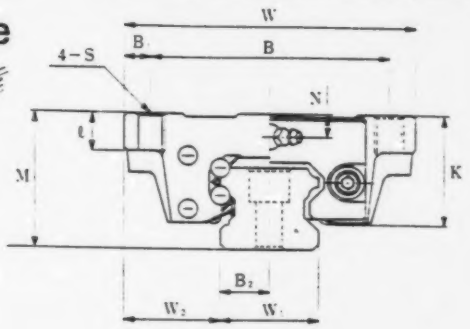
Common specifications to above models:

Supply current required: 2-20 mA, constant
Supply voltage required: +18 to +30 VDC
Output bias level: 9-12 VDC (3-5 VDC optional on some models. Check factory for details.)
Overload recovery: 10 μ seconds

Maximum transverse sensitivity: 5%
Linearity: +/-1% full scale
An NBS traceable calibration certificate is supplied with instrument at no extra charge.

# THK LM Guide HSR...TA TB Type






**HSR···TA**

| Model No | Bearing dimensions mm | | | | | | | | | | | | Grease nipple |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Width W | B | $B_1$ | Length L | C | Height M | S × ℓ | H | T | K | N | E | |
| **HSR 15TA**<br>**HSR 15TB** | 47 | 38 | 4.5 | 53.5 | 30 | 24 | M 5 × 7<br>—— | —<br>4.5 | —<br>7 | 19.4 | 4.5 | 5.5 | Drive-in nipple |
| **HSR 25TA**<br>**HSR 25TB** | 70 | 57 | 6.5 | 79 | 45 | 36 | M 8 × 10<br>—— | —<br>7 | —<br>10 | 29.5 | 6 | 12 | |
| **HSR 30TA**<br>**HSR 30TB** | 90 | 72 | 9 | 94 | 52 | 42 | M 10 × 10<br>—— | —<br>9 | —<br>10 | 35 | 7 | 12 | B-M6F |
| **HSR 35TA**<br>**HSR 35TB** | 100 | 82 | 9 | 105 | 62 | 48 | M 10 × 13<br>—— | —<br>9 | —<br>13 | 40 | 8 | 12 | |
| **HSR 45TA**<br>**HSR 45TB** | 120 | 100 | 10 | 133 | 80 | 60 | M 12 × 15<br>—— | —<br>11 | —<br>15 | 50 | 10 | 16 | |
| **HSR 55TA**<br>**HSR 55TB** | 140 | 116 | 12 | 159 | 95 | 70 | M 14 × 17<br>—— | —<br>14 | —<br>17 | 57 | 11 | 16 | B-PT⅛ |
| **HSR 65TAX**<br>**HSR 65TBX** | 170 | 142 | 14 | 186 | 110 | 90 | M 16 × 23<br>—— | —<br>16 | —<br>23 | 76 | 19 | 16 | |

## *1. Equal load capacities in four directions*

Each row of balls is designed to have equal load ratings against all loads applied from all directions – radial, reverse-radial and dual-lateral – to a single bearing, thereby permitting a wide variety of applications.

## *2. Greatly improved load rating*

The load rating has been greatly improved by the adoption of larger balls and an increase in the number of effective balls as compared with the conventional NSR Type.

**Ratio of load rating**

(comparison between HSR45TB and NSR40TBC)

| | Radial direction | Reverse-radial direction | Lateral direction |
|---|---|---|---|
| Basic Dynamic Load Rating | C × 1.6 | $C_L$ × 2.7 | $C_T$ × 3.0 |
| Basic Static Load Rating | $C_0$ × 1.8 | $C_{0L}$ × 3.6 | $C_{0T}$ × 4.2 |

## GENERAL DESCRIPTION

The OMEGA LV-10 Series Level Switches feature a small float displacement, especially suited for narrow or restricted areas. A standard 1/8" NPT male fitting allows for quick installation in either the top or bottom of the tank or vessel. A sealed SPST switch provides consistent accuracy and high repeatability with the effects of shock, vacuum or vibration minimized. Extremely versatile, the switch is user selectable as normally open (N.O.) or normally closed (N.C.) by simply removing the retaining clip and inverting the position of the float.

For intermediate float displacement, the LV-20 Series will yield long life and greater stability for a broad range of level monitoring requirements. The LV-30 Series larger float displacement is intended for use with liquids of high viscosity, and is well suited for harsh environments. Both models share the standard features of the LV-10.

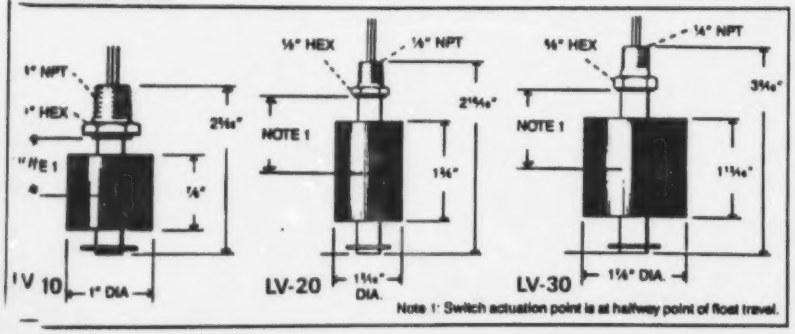
## SPECIFICATIONS

| | |
|---|---|
| **STEM MATERIAL:** | Brass, models LV-10, LV-20, LV-21, LV-30, LV-31; 316SS, models LV-11, LV-22, LV-23, LV-32, LV-33 |
| **FLOAT MATERIAL:** | Buna N |
| **OTHER WETTED MATERIAL:** | 316SS and Hysol |
| **OPERATING TEMPERATURE:** | Water: 0° to 180°F; Oil: 0° to 230°F |
| **PRESSURE RATING:** | 150 psi |
| **MOUNTING:** | 1/8" NPT for LV-10 & LV-20 Series; 1/4" NPT for LV-30 Series |
| **WRENCH HEX (or Flats Size):** | 1/2" for LV-10 & LV-20 Series; 5/8" for LV-30 Series |
| **FLOAT DIA:** | 1" for LV-10 Series; 1 3/16" for LV-20 Series; 1 7/8" for LV-30 Series |
| **SWITCH:** | SPST |
| **SWITCH ACTUATION:** | Approx. ½ the distance from end of stem to mounting, or at halfway point of float travel. |
| **SWITCH RATING:** | Models LV-10, LV-11: 10VA; Models LV-20, LV-22, LV-30, LV-32: 20VA; Models LV-21, LV-23, LV-31, LV-33: 100VA |
| **LEAD WIRES:** | 22 awg 24" polymeric for LV-10 and LV-20 Series; 18 awg 24" polymeric for LV-30 Series |
| **SPECIFIC GRAVITY OF FLOAT:** | LV-10 Series, .50; LV-20 Series, .59; LV-30 Series, .43 |

**NOTE**

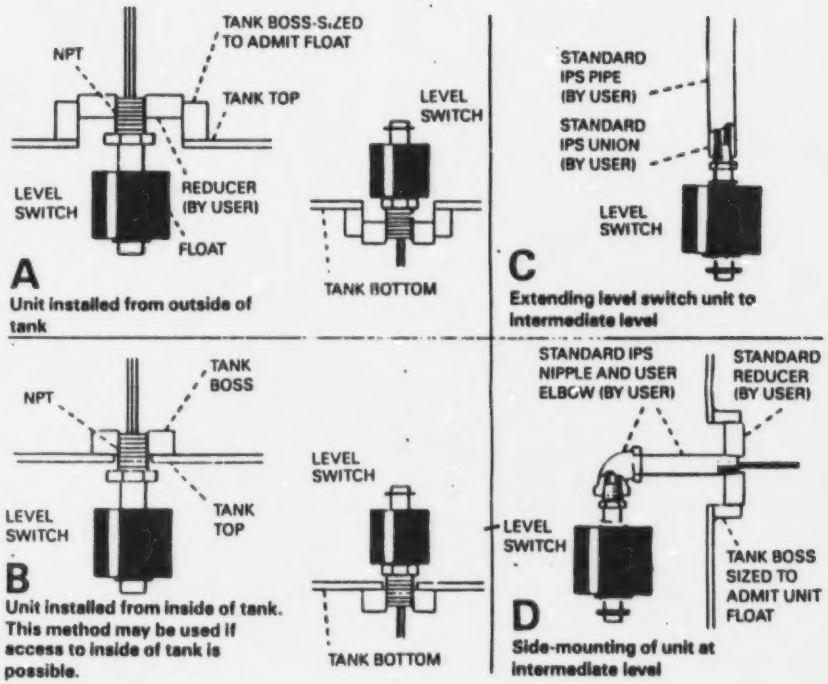
To determine minimum fluid specific gravity, add 0.1 to float specific gravity in clean liquids and 0.3 to float specific gravity in dirty water or viscous liquids.

## DIMENSIONS



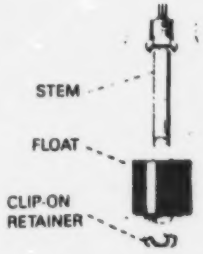

## INSTALLATION

Install units vertically in tank top or bottom using Methods A, B, C or D (below).
Note: Units will operate normal[illegible] ed up to 30.

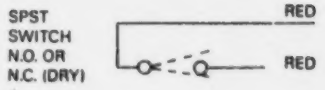



## REVERSING SWITCH OPERATION

The switch is user selectable as normally open or normally closed (dry). Simply remove the retaining clip and invert the position of the float. It is not necessary to disturb the installation.



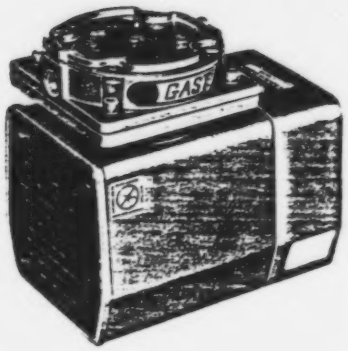

## WIRING DIAGRAM



# Diaphragm Air Compressors

- Oil-less
- Motor Mounted
- Special Motors Available

Various brand names motors are furnished on any model at the discretion of Gast Mfg. Corp.



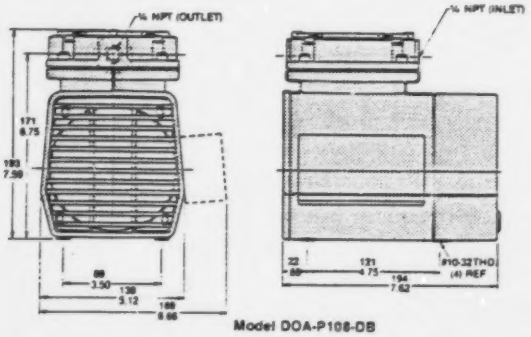

## Model DOA

**Oil-less, Motor Mounted**
**(4 Pole PSC Motors)**

**INCLUDES**
- Permanent Split Capacitor Motor
- Capacitor (Unattached or Attached) AF873
- Thermotector

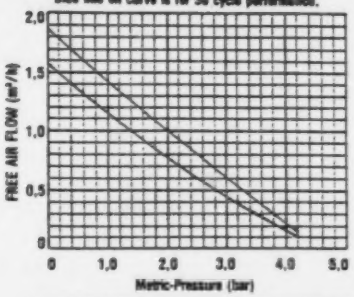
**RECOMMENDED**
- Rubber Feet AF584A (order 4)
- Carrying Handle AF885
- Repair Kit K294A
- Pressure Relief Valve AF887
- Gauge AF583

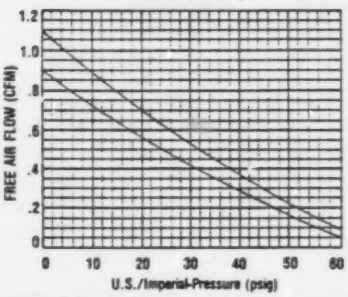
**Note: On all drawings**
**Metric**
**U.S./Imperial** (Dimensions for reference only)




Model DOA-P108-DB

Black line on curve is for 60 cycle performance.
Blue line on curve is for 50 cycle performance.




| Model No. Chart | Motor | RPM 60 cycle | RPM 50 cycle | HP | kW | Net Wt. lbs. | Net Wt. kg |
|---|---|---|---|---|---|---|---|
| A* DOA-P108-DB | 115-60/50-1 | 1575 | 1275 | 1/8 | .09 | 14.56 | 6.6 |
| A* DOA-P108-DD | 230-60/50-1 | 1575 | 1275 | 1/8 | .09 | 14.56 | 6.6 |
| B* DOA-P110-DD | 230-60/50-1 | 1575 | 1275 | 1/8 | .09 | 14.56 | 6.6 |
| C* DOA-P111-DD | 230-60/50-1 | 1575 | 1275 | 1/8 | .09 | 14.56 | 6.6 |
| A* DOA-P112-DD | 230-60/50-1 | 1575 | 1275 | 1/8 | .09 | 14.56 | 6.6 |
| C* DOA-P111-DG | 240-50-1 | | 1275 | 1/8 | .09 | 14.56 | 6.6 |
| A* DOA-P112-DG | 240-50-1 | | 1275 | 1/8 | .09 | 14.56 | 6.6 |

A* Capacitor unattached pigtail wires
B* Capacitor mounted in mini-box, pigtail wires (European color-coded wires) no plug
C* Capacitor mounted in mini-box, two meter cord (European color coded) no plug

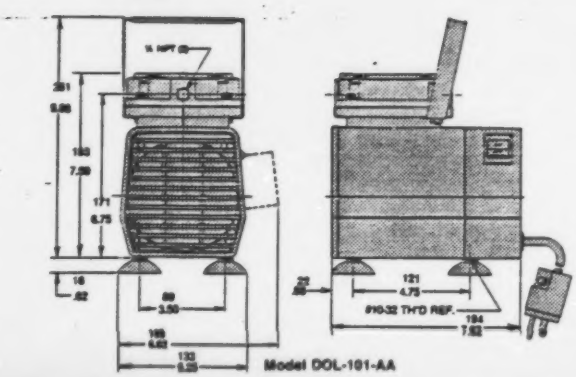
## Model DOL Series

**Oil-less, Motor Mounted (Medical & Dental)**

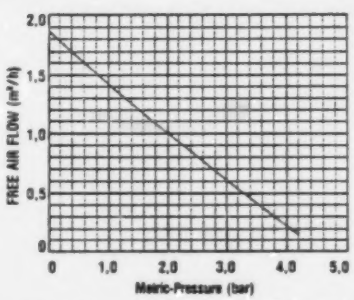
**INCLUDES**
- Thermotector
- Carrying Handle
- On/Off Switch
- Rubber Feet
- Cord and Hospital Grade Plug
- Filter (Internal)

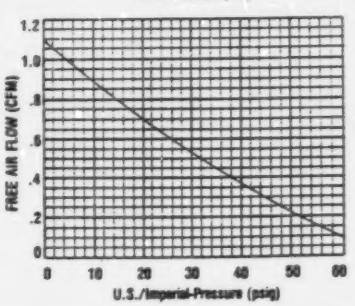
**RECOMMENDED**
- Pressure Relief Valve AF887
- Repair Kit K294A

**Note: On all drawings**
**Metric**
**U.S./Imperial** (Dimensions for reference only)




Model DOL-101-AA




| Model No. Chart | Motor | RPM | HP | kW | Net Wt. lbs. | Net Wt. kg |
|---|---|---|---|---|---|---|
| *DOL-101-AA | 115-60-1 | 1575 | 1/8 | 0.09 | 14.75 | 6.70 |
| **DOL-101-DB | 115-60-1 | 1575 | 1/8 | 0.09 | 14.75 | 6.70 |

*Shaded pole motor
**Permanent split capacitor motor with capacitor mounted on unit

This model is U/L listed under STD. #544 and CSA approved for "medical and dental equipment."

# MINIATURE FILTER, REGULATOR AND LUBRICATOR

## INSTALLATION, OPERATING AND MAINTENANCE INSTRUCTIONS

### INSTALLATION

Before installing, blow out pipe line to remove scale and other foreign matter. This unit has DRYSEAL pipe threads; use pipe compound or tape sparingly to male threads only. Install item in pipe line so that air will flow in direction of arrow stamped on body, install as near as possible to equipment serviced. Filters and lubricators must be installed with bowl in a vertical position. Combination units are factory assembled for left-to-right flow.

### ADJUSTMENT

REGULATOR - REDUCED PRESSURE ADJUSTMENT

To adjust reduce pressure settings, loosen lock screw in center of knob and turn knob clockwise to increase pressure setting and counter clockwise to lower setting. With relieving-type regulators the reduced pressure follows adjustment of the screw with non-relieving regulators adjustment for lower reduced pressure will not be obtained until the reduced pressure system is "bled-off" or until air flow starts.

LUBRICATOR - FILLING AND ADJUSTMENT

To fill, shut off air supply, remove either of the two fill plugs and fill with oil to within ¼" of the top of the bowl. For most conditions, the use of a high quality SAE #10 (SUV 150-200 sec. 100°F) is recommended. Other oils, as specified by the maker of the equipment to be lubricated, may be used, if not heavier than SAE #30. Caution is advised in the use of oils containing additives as many such agents are not compatible with plastic bowls. Start equipment and operate a few minutes to permit system to fill. Check lubrication of the equipment by holding the thumbnail or a mirror near the exhaust opening - a slight film of oil should be deposited each exhaust cycle. A heavy film indicates over-lubrication and the drops per minute should be reduced by turning adjusting screw clockwise. Clockwise rotation of adjusting screw decreases lubrication; counter clockwise rotation increases lubrication. DO NOT turn adjusting screw more than 1½ turns counter clockwise from the closed position.

### MAINTENANCE - CLEANING

NOTE: To clean, it is not necessary to remove lubricator from line. Refer to drawing as guide in reassembly. CAUTION: Remove air pressure from air line prior to disassembly.

### FILTER

To maintain maximum filtering efficiency and to avoid excessive pressure drop the filter must be kept clean. Turn drain valve to drain off any bowl accumulation before it reaches level of lower baffle. A visible coating of dirt or condensate on the filter element or an excessive pressure drop indicates cleaning is necessary. Wash filter element in white kerosene and blow out body with compressed air. Clean bowl with household soap or white kerosene.

### REGULATOR

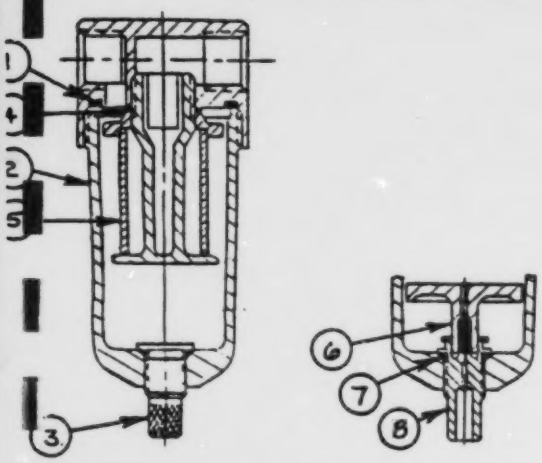
If the air supply is kept clean the regulator should provide long periods of uninterrupted service. Erratic regulator operation or loss of regulation is most always due to dirt in the disc area. To clean, shut off air line pressure and disassemble the regulator. Refer to drawing on reverse side as a guide to disassembly and subsequent reassembly. Clean parts with white kerosene and blow out body with compressed air. When reassembling make sure the seat is firmly in place and that the valve assy.fits into center hole of diaphragm assembly. If diaphragm assembly is replaced make sure valve stem fits into its center hole tighten bonnet slightly more than hand tight (up to 60 inch lbs. torque).

### LUBRICATOR

If air and oil are kept clean and the oil level never allowed below end of dip tube, the lubricator should provide long periods of unattended service. If the oil drip rate diminishes or requires continual readjustment, shut off the air supply, remove the bowl and apply compressed air to the lower end of the dip tube to make sure that the oil delivery system is free and clear of impediment. Wash any parts requiring cleaning with white kerosene and reassemble unit. CAUTION: Lubricator bowl should be cleaned with household soap or white kerosene.

**WARNING! Never use these polycarbonate plastic bowls on air supplied by a compressor lubricated with synthetic oils or oils containing phosphate esters or chlorinated hydrocarbons. They can carry-over into the air distribution system and chemically attack and possibly rupture the bowls. On these applications use a metal bowl. Also, do not expose these polycarbonate plastic bowls to materials such as carbon tetrachloride, trichlorethylene, acetone, paint thinner, cleaning fluids, or other harmful materials, for they too will craze and/or rupture the bowl. If materials harmful to polycarbonate are present either outside or inside the bowl, use a metal bowl.**

# REPLACEMENT PARTS

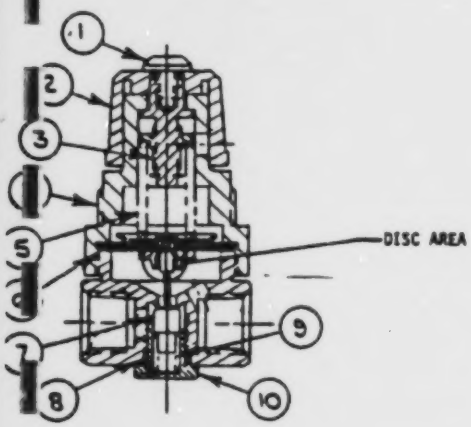



## MINIATURE FILTER

Plastic Bowl - Maximum Pressure 150 PSIG
Maximum Temperature 120°F
Metal Bowl - Maximum Pressure 300 PSIG
Maximum Temperature 200°F

| ITEM | DESCRIPTION | ORDER NUMBER |
|---|---|---|
| 1<br>2<br>3 | Bowl Gasket *<br>Bowl<br>Drain Assembly | Bowl Kits<br>5421-0950 (Plastic)<br>5441-8000 (Metal) |
| 4<br>5 | Vane Plate Gasket<br>Filter Element | Filter Element Kits<br>5441-8003 (5 Micron)<br>5441-8004 (20 Micron) |
| 6<br>7<br>8 | Piston Assembly<br>O'Ring<br>Drain | Piston Drain Kit<br>5441-8005 |

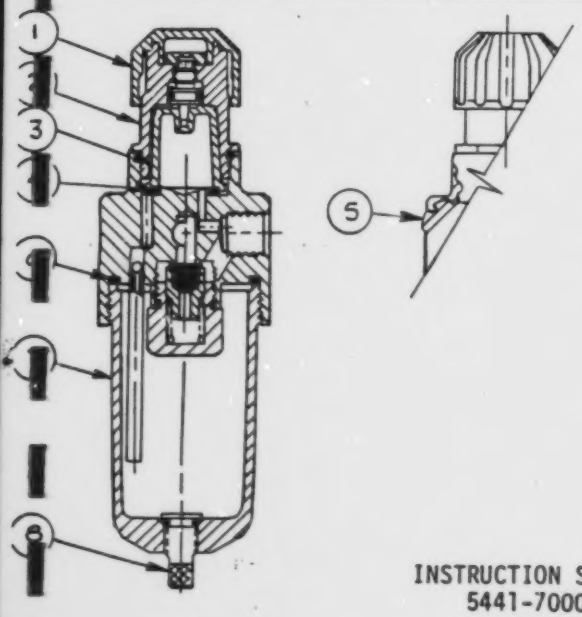
*SOLD SEPARATELY AS 5421-0930




## MINIATURE REGULATOR

Maximum Inlet Pressure 300 PSIG
Maximum Temperature 120°F

| ITEM | DESCRIPTION | ORDER NUMBER |
|---|---|---|
| 1<br>2<br>3<br>4 | Screw<br>Knob<br>Adjusting Screw Assembly<br>Spring Cage | Spring Cage & Knob Kit<br>5451-8000 |
| 5 | Spring 0-25 PSIG<br>Spring 0-60 PSIG<br>Spring 0-125 PSIG | 5421-0130<br>5421-0140<br>5421-0010 |
| 6<br>7<br>8 | Diaphragm Assembly<br>Valve Assembly<br>O'Ring | Service Kits<br>5420-0195 (Relieving)<br>5421-0240 (Non-Relieving) |
| 9 | Bottom Spring | 5420-0026 |
| 10 | Bottom Plug | 5420-0600 |




## MINIATURE LUBRICATOR

Plastic Bowl - Maximum Pressure 150 PSIG
Maximum Temperature 120°F
Metal Bowl - Maximum Pressure 300 PSIG
Maximum Temperature 200°F

| ITEM | DESCRIPTION | ORDER NUMBER |
|---|---|---|
| 1<br>2<br>3<br>4 | Adjusting Cap<br>Sight Glass Ass'y<br>Drip Spout<br>O'Ring | Sight Dome Kit<br>5421-8002 |
| 5 | Fill Plug | 5421-7005 |
| 6<br>7<br>8 | Bowl Gasket *<br>Bowl<br>Drain Assembly | Bowl Kits<br>5421-0950 (Plastic)<br>5441-8000 (Metal) |

* SOLD SEPARATELY AS 5421-0930

INSTRUCTION SHEET
5441-7000

SBWF-1030
REV. SEPT. 84

**Schrader Bellows Division**
Scovill
200 West Exchange Street, Akron, Ohio 44309
(216) 375-5202

# AI 2056/1 LVDT SIGNAL CONDITIONER BOARD

## GENERAL

This LVDT Signal Conditioning Unit consists of a B-260 PC Board mounted in a NEMA 4 Enclosure. Input Connections, 4-20mA Output Connections, Power Input and Fuse are accessible by lifting the Enclosure lid.

## INSTALLATION

The unit should be connected to a clean source of 120 Volts A.C. 60 Hz. These connections are made at the terminal strip labelled Line and Neutral.

Transducer connections are made on the opposite terminal strip in accordance with the wiring diagrams on Dwg. 1518.

An Excitation Trimmer is available on the board. It is factory preset at 3V rms and is adjustable from 1V to 7V rms.

Span and Zero potentiometers are readily accessible and are labelled. A gain range link is also available to increase the gain by approximately 10. The link is factory installed in the low gain position.

## CALIBRATION

The following set-up procedure should be adopted. Set the sensor in the position for which you will require 4mA. Adjust the output from the module to ZERO (not 4mA). Apply full range to the sensor and adjust the output to 16mA (not 20mA), then return sensor to zero and adjust reading to 4mA. Check the full range which should now be reading 20mA and adjust if necessary. Check both the 4mA and 20 mA readings again as there will be some small interaction.

See Dwg. 1518 for wiring connections.

)PERATION

Refer to drawing 1516A

Multiple power supplies are available according to the options described.

In a standard module with A.C. power supplies, 115V, 60 Hz., power is applied, live to Pins 1 through 4 and neutral to Pins 7 through 10, on the edge connector PL1. R11 is linked (=0 ohms) and power is applied to the primary of T1, either Hammond 161F20 or 229A20. D1, D2, D4 & D5 form a full wave voltage doubler rectifier using C1, C2, C10 & C11 as reservoir capacitors, to give +/-30V approximately off load.

Series pass transistor Q1 is biased `ON' by R45 and passes current to D7 via R7. D7 is a precision voltage reference of 6.2 volts running at 7.5 mA. This voltage is applied to one input of U1B. At the same time a proporation of the +15V supply line also equal to 6.2V as fixed by the two resistors R5 & R6 is applied to the other input of U1B. The difference between the two voltages is amplified by U1B and applied to Q2 base turning on Q2 and reducing the voltage to the base of Q1 to the level required to provide 15V at its emitter (15.7V approx.). The negative feedback thus provided ensures high stability of the supply voltage. C8 provides a high degree of feedback of high frequency noise and ripple and C12 maintains a low supply impedance at higher frequencies.

Similarly R46 biasses on Q6 and current passes to R9. R8 and R9 are equal and any difference in voltage between the two supplies appears at the input of U1A which amplified this error and applies it to the base of Q4. Q4 turns on and reduces the voltage at the base and therefore at the emitter of Q6, such that the negative supply voltage is equal to that of the positive supply. C9 ensures full feedback of ripple and noise and C13 ensures low output impedance at higher frequencies.

The circuit of U3BQ9 and Q10 form the transducer drive circuit. This is a power oscillator using multiple phase shift. U3B drives Q9 and Q10, complementary emitter followers. Feedback via the phase shifting network C23 & R12, C22 & R13 & C17 results in overall positive feedback and oscillation at a frequency determined by the network (approx. 2500Hz.). Negative feedback via R15 & R14 would prevent oscillation however if not reduced by the shunting effect of Q11. This is controlled by turning on Q11 enough to hold the oscillation at just the level required to provide the desired drive.

:ontinued...../3

OPERATION continued...../

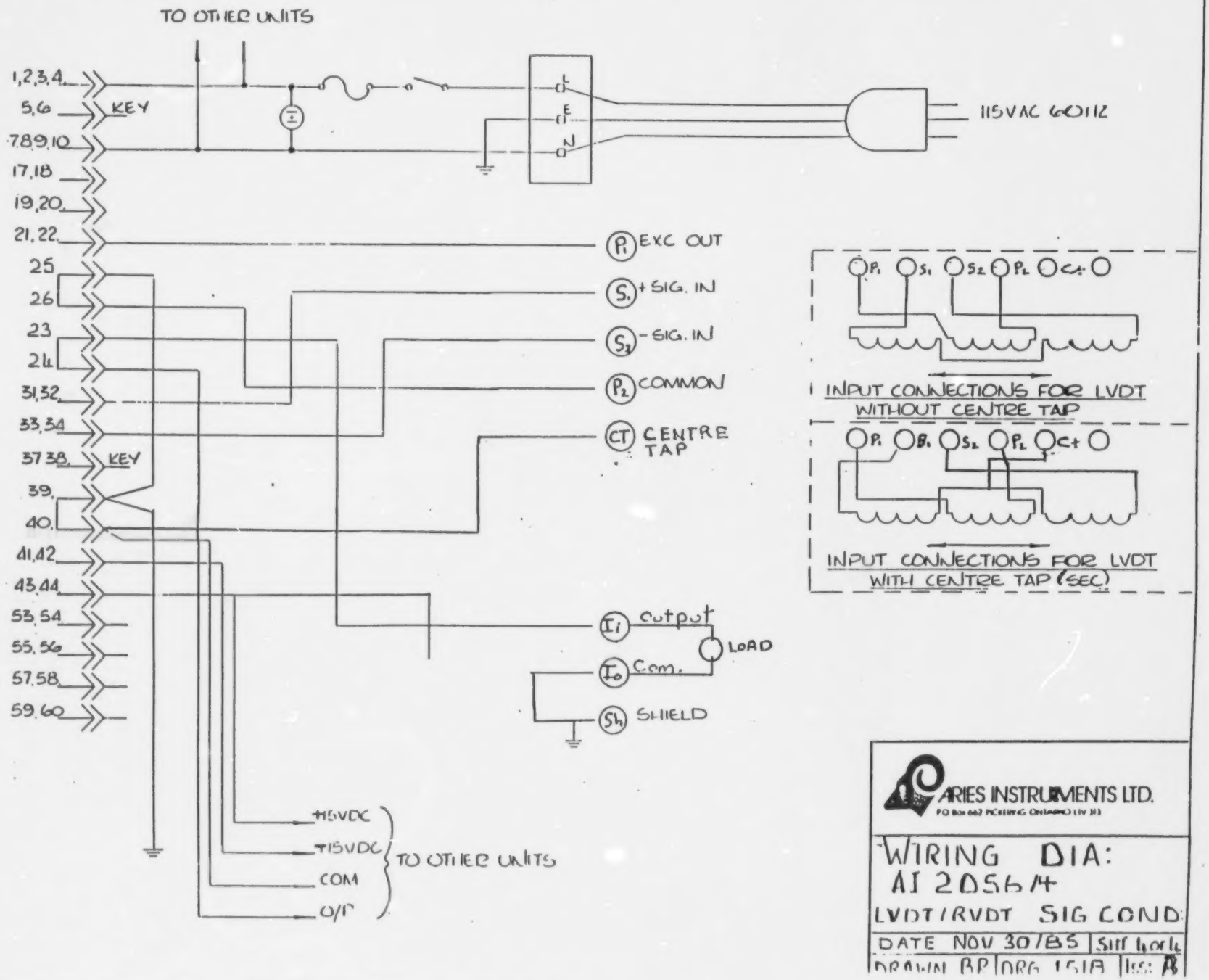
The two secondaries of the transducer are connected with their outputs in opposition so that the net output is the differential signal. The centre tap formed is connected to common. On the premise that holding the sum of the outputs of the secondaries constant will improve the stability of the difference signal, the outputs from the secondaries are summed first by R16 & R17 to the input of inverter U2C and secondly to the input of U2D via R22 & R23.

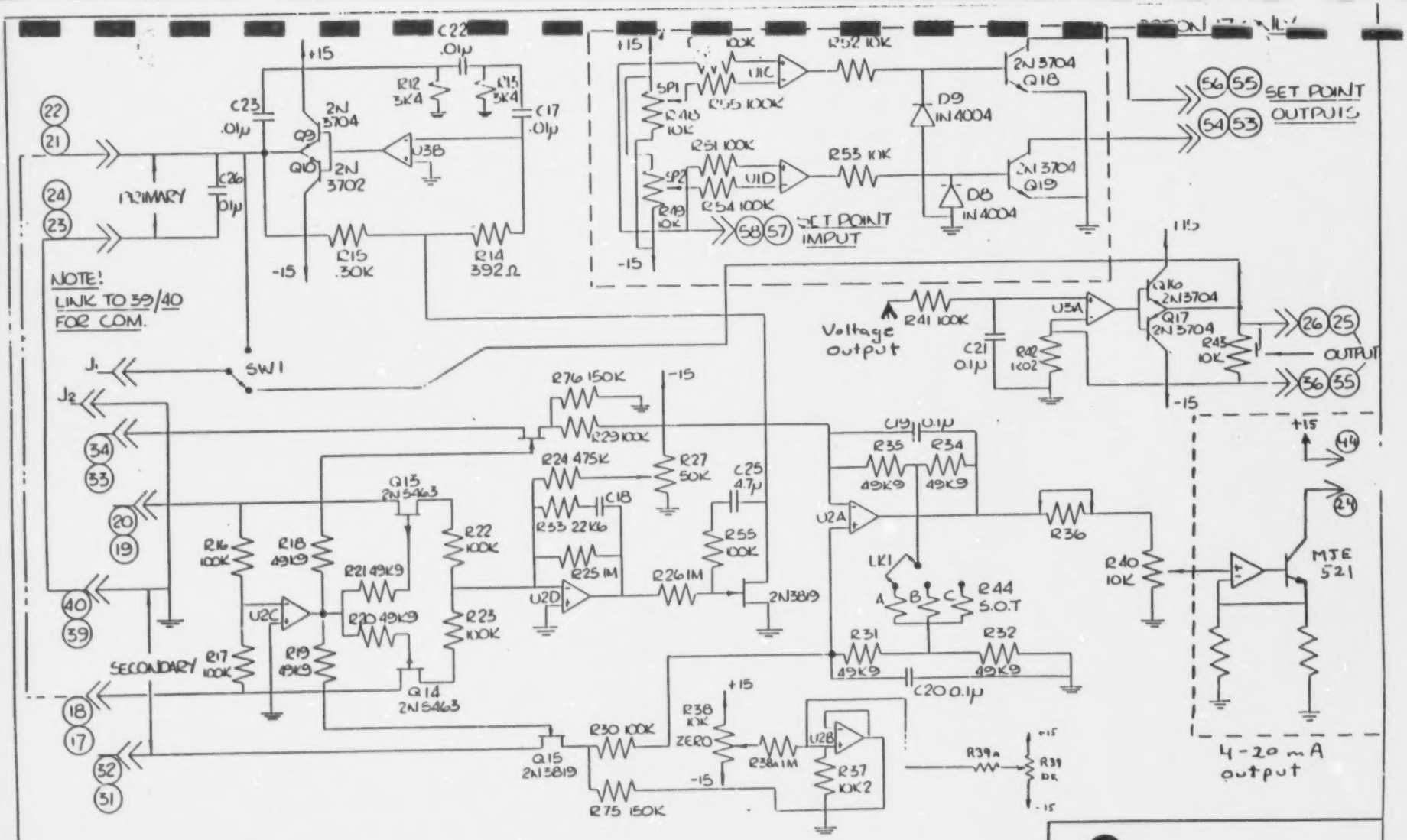
Inverter U2C operates without feedback and provides a square wave of approximately 25V peak to peak at its output, in phase with the secondary signal. This square wave is used to switch Q13 & Q14, P-channel FETS, and Q12 & Q15 N-channel FETS, so that the positive half cycle of the signal is applied through R22 & R23 to the input of U2D. The average positive signal at this input is compared with the outout of R27, the excitation trimmer on the module front panel. Any error is amplified by U2D and applied to turn off Q11 as a form of AGC. This method of control holds the phase shift oscillator just oscillating and a very pure output sine wave of stable frequency is produced. R55 & C55 smooth out ripple from the signal and linearize the resistance of Q11 which with a net zero D.C. between drain and source and a very low A.C. signal acts purely as a voltage variable resistor.

During the negative half cycle of the signal Q12 & Q15 are turned on. The two secondary signals are applified to the inputs of Z2A and are compared and the difference amplified with a gain controlled in increments of 10 by the position of LK1.

An offset voltage is added to the non-inverting input of U2A, derived from R38 the front panel ZERO potentiometer. This voltage may further br adjusted by R39 which may be increased to reduce the range of offset available which in turn allows finer adjustment of the offset voltage if desired. It should be noted that the gain of the circuit is unaffected by change of offset and that the offset effective at the output of U2A is unaffected by change of gain. However, if the gain is subsequently increased the effect of the offset at the unit output is equally increased and R37 may be used if required to modify this effect.

The output of U2A is applied to the potentiometer R40, which is used to adjust present gain figures. The output is further filtered by R41 & C21 and applied to a follower consisting of U3A, Q16 & Q17 which also provides extra gain using the 1 span control R43, arranged to provide a range of 5 to 1 when uncalibrated (option /01B) and 11:1 when calibrated (option /04C).


TO OTHER UNITS
1,2,3,4,
5,6
KEY
7,8,9,10
17,18
19,20,
21,22,
25
26
23
24
31,32,
33,34
37,38,
KEY
39,
40,
41,42
43,44
53,54
55,56
57,58
59,60
L
E
N
115VAC 60HZ
P1 EXC OUT
S1 + SIG. IN
S2 - SIG. IN
P2 COMMON
CT CENTRE TAP
I1 output
LOAD
I0 Com.
SH SHIELD
+15VDC
-15VDC
COM
O/P
TO OTHER UNITS
P1 S1 S2 P2 C1
INPUT CONNECTIONS FOR LVDT WITHOUT CENTRE TAP
P1 B1 S2 P2 C1
INPUT CONNECTIONS FOR LVDT WITH CENTRE TAP (SEC)
ARIES INSTRUMENTS LTD.
WIRING DIA:
AI 2056/4
LVDT/RVDT SIG COND.
DATE NOV 30/85
DRAWN BP
DRG 1618
ISS: B



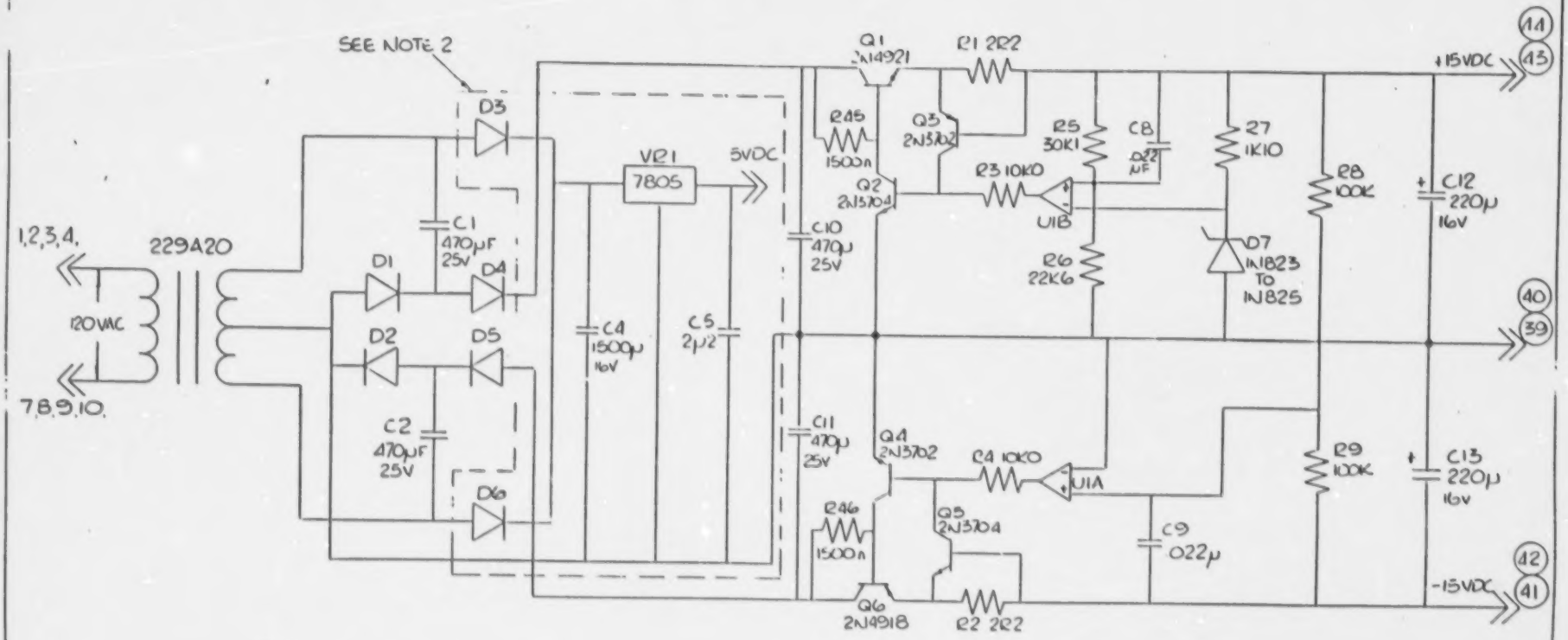

NOTE!
1. R44 A 23K2 / B 4K64 / C 931 } OPTION 01 ONLY SELECT ON TEST FOR NON-STANDARD GAIN RANGES
2. R33, C18 S.O.T (ON 3900pf TYPICAL)
3. C26 IF REQUIRED ONLY (S.O.T)
4. LK MAY BE REPLACED BY FRONT PANEL SWITCH, IF REQUESTED
5. R27, R38, R39, R13, R49 VALUES 10K TO 100K ACCORDING TO AVAILABILITY

ARIES INSTRUMENTS LTD.
P.O. Box 662 PICKERING ONTARIO L1V 2T3

# SCHEMATIC AI 2056/1

LVDT / RVDT SIG COND.

| | | |
|---|---|---|
| DATE NOV 30 / 85 | SHT 1 of 1 | |
| DRAWN B.R | DWG # 1516 | ISS: A |




NOTE!

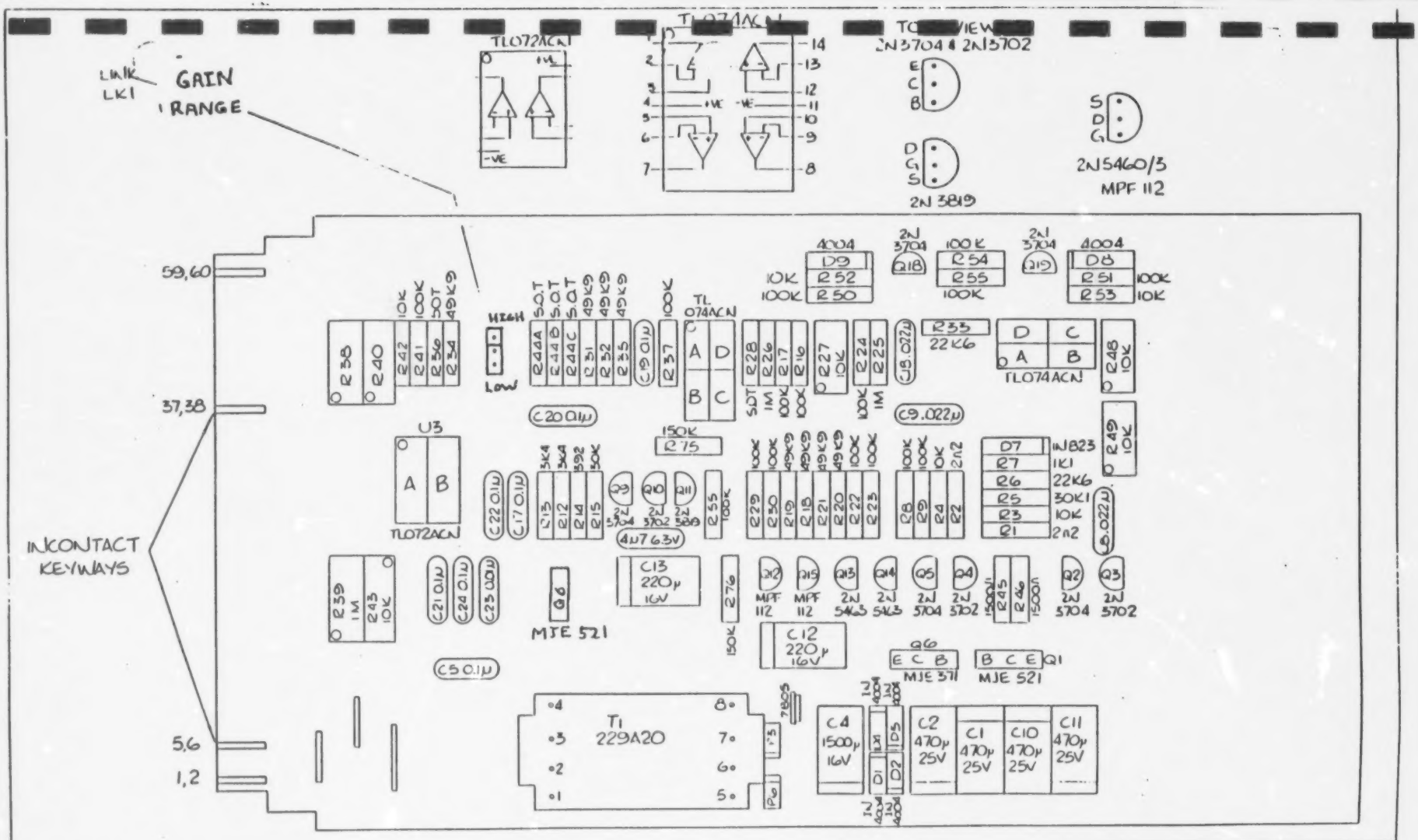
1. ALL DIODES IN 4004, UNLESS OTHERWISE STATED
2. COMPONENTS INSIDE BOX NORMALLY OMITTED

ARIES INSTRUMENTS LTD.
PO Box 662 PICKERING ONTARIO L1V 2T3

POWER SUPPLY
AI 2056/1
LVDT/RVDT SIG COND

DATE NOV 30/85 | SHT 1 of 4

DRAWN BP | DOC. NO. | ISS: A




NOTE! 1. R49, R48, R43, R38, R27 OR R40, MAY BE REPLACED BY TRIMMERS ON FRONT PANEL.
2 Q12 AND Q15 MAY BE EITHER MPF 112 OR 2N3819
3 R27, R38, R39, R40, R48 AND R49 VALUES MAY BE CHANGED FROM 10K TO 100K

ARIES INSTRUMENTS LTD.
P.O Box 662 PICKERING ONTARIO L1V 3T3

BOARD LAYOUT
AI 205611
LVDT/RVDT SIG COND

| | | |
|---|---|---|
| DATE NOV 30/85 | | SHT 3 OF 4 |
| DRAWN B.R | DWG# 1517 | ISS: A |

# AI13 ANALOG INPUT SYSTEM

## DATA ACQUISITION (A TO D) MODULE FOR APPLE II

- A precision voltage reading interface.
- Diskette starts you with programs that work.
- Program selects the input - 16 separate channels.
- Program selects the scaling - 8 full-scale ranges!
- Accurate - true 12-bit 0.024% resolution.
- Fast - makes a reading in 20 microseconds.
- Sample-and-Hold circuitry captures dynamic signals.
- External trigger synchronizes to other equipment.

The AI13 Analog Input System is a high-performance 12-bit data acquisition system for the Apple II computer. It plugs directly into one of the Apple expansion slots and gives the Apple the ability to make precision voltage measurements. Its accuracy and flexibility create a laboratory capability for the Apple II which matches systems costing 3 to 10 times as much.

### WHAT THE AI13 INCLUDES

The AI13 comes complete with cabling, a well-written manual, and most importantly, an extensive software diskette including working examples of 5 different acquisition techniques. The example programs are directly usable, and they also serve as starting points for development of custom software. The AI13 also includes a 1-year warranty and full support by an experienced engineering and technical staff.

### WHAT YOU CAN PLUG INTO AN AI13

With the AI13, any instrument or sensor producing an electrical signal becomes an Apple II input device. Software selects the input range, so sensor output ranges from ± 5 Volts down to 0-100 milliVolts can be accomodated. Operation is fast, allowing acquisition of DC through audio frequencies.

### HOW YOU MAKE A READING

The AI13 is easily used from any programming language. Select channel and range by a single store operation, then read the result in 2 bytes directly from the AI13. Software is in complete control of both the order and the speed with which the channels are read.

### HOW YOU PROGRAM A HIGH-PERFORMANCE APPLICATION

The AI13 fully supports high-performance programming techniques, such as high speed Assembly language sampling. It can signal that a data conversion is complete either by setting a flag for the program or by creating a processor interrupt when done. Analog readings may also be started by an external trigger pulse. Examples of all these techniques are included on the software diskette.

# AI13 PERFORMANCE SPECIFICATIONS

## ANALOG SPECIFICATIONS

Input Full Scale Ranges (milliVolts):

| | | | |
|---|---|---|---|
| 0 to 5000 | 0 to 500 | -5000 to 5000 | -500 to 500 |
| 0 to 1000 | 0 to 100 | -1000 to 1000 | -100 to 100 |

Input Impedance: 10 MegOhms
Crosstalk from unselected channel: -95db

Input Protection: Inputs can withstand ± 22V (± 10V with Apple OFF.)

## CONVERSION SPECIFICATIONS

Resolution: 12 Bits, 4096 steps
Coding: Binary, 0 to 4095 full-scale.
0 is min, 4095 is max value.
Overrange Processing: Values greater than max will appear as 4095.
Values less than min will appear as 0.
Deviation from ideal step size: 0.024% maximum
Deviation from ideal straight line: 0.024% typical

## CONVERSION TIMING:

Selection & Sampling: 6 microseconds
Hold and Conversion: 13 microseconds
Total conversion time: 20 microseconds
Sampling Aperture: 125 nanoseconds

Settling time delays:
Channel switch, 5V or 1V scales: none.
Range switch, 5V or 1V scales: none.
Channel switch, .5 or .1 scales: 45 microseconds.
Range switch, .5 or .1 scales: 45 microseconds.

## PHYSICAL SPECIFICATIONS

Logic board: 2.75 X 8.0" with gold edge connector.
Analog board: 1.62 X 4.25 X 4.62" steel cabinet
Board Material: .0625" FR fiberglass, UL listed construction
Input connector: 34-pin ribbon or individual inputs
Cable: 34-conductor twisted-pair ribbon

## ELECTRICAL REQUIREMENTS

Internal Power: Drawn from Apple Supply,
5V @ 45mA, 12V @ 19mA., -12V @ 16mA.
External Power: None required.
External Trigger: Positive or Negative Edge TTL

# SPECIFICATIONS ($T_A$ = +25°C, rated power supplies unless otherwise noted.)

| Model | AD DAC30 Min | AD DAC30 Typ | AD DAC30 Max | AD DAC35 Min | AD DAC35 Typ | AD DAC35 Max | AD DAC37 Min | AD DAC37 Typ | AD DAC37 Max | Units |
|---|---|---|---|---|---|---|---|---|---|---|
| TECHNOLOGY | | Monolithic | | | Monolithic | | | Monolithic | | |
| DIGITAL INPUT | | | | | | | | | | |
| Binary—CBI | | | 12 | | | 12 | | | 12 | Bits |
| BCD—CCD | | | | | | | | | | Digits |
| Logic Levels (TTL Compatible) | | | | | | | | | | |
| $V_{IH}$ (Logic "1") | +2.0 | | +5.5 | +2.0 | | +5.5 | +2.0 | | +5.5 | V |
| $V_{IL}$ (Logic "0") | 0 | | +0.8 | 0 | | +0.8 | 0 | | +0.8 | V |
| $I_{IH}$ ($V_{IH}$ = 5.5V) | | | 250 | | | 250 | | | 250 | μA |
| $I_{IL}$ ($V_{IL}$ = 0.8V) | | | 100 | | | 100 | | | 100 | μA |
| TRANSFER CHARACTERISTICS | | | | | | | | | | |
| ACCURACY | | | | | | | | | | |
| Linearity Error @ +25°C | | | | | | | | | | |
| CBI | | | ±1/2 | | | ±1/2 | | | ±1/2 | LSB[1] |
| CCD | | | | | | | | | | LSB |
| $T_A$ @ $T_{min}$ to $T_{max}$ | | ±1/4 | ±1/2 | | ±1/4 | ±1/2 | | ±1/2 | ±3/4 | LSB |
| Differential Linearity Error @ +25°C | | | | | | | | | | |
| CBI | | | ±3/4 | | | ±3/4 | | | ±3/4 | LSB |
| CCD | | | | | | | | | | LSB |
| $T_A$ @ $T_{min}$ to $T_{max}$ | | | ±3/4 | | | ±1 | | | ±1 | LSB |
| Gain Error[2] | | ±0.1 | ±0.3 | | ±0.1 | ±0.2 | | ±0.1 | ±0.2 | %FSR[3] |
| Offset Error[2] | | ±0.05 | ±0.15 | | ±0.05 | ±0.1 | | ±0.05 | ±0.1 | %FSR[3] |
| Temperature Range for Guaranteed Monotonicity | 0 | | +70 | −25 | | +85 | −55 | | +125 | °C |
| DRIFT ($T_{min}$ to $T_{max}$) | | | | | | | | | | |
| Total Bipolar Drift, max (includes gain, offset, and linearity drifts) | | | ±20 | | | ±20 | | | ±30 | ppm of FSR/°C |
| Total Error ($T_{min}$ to $T_{max}$)[4] | | | | | | | | | | |
| Unipolar | | ±0.08 | ±0.15 | | ±0.12 | ±0.2 | | ±0.18 | ±0.3 | % of FSR |
| Bipolar | | ±0.06 | ±0.10 | | ±0.08 | ±0.12 | | ±0.14 | ±0.24 | % of FSR |
| Gain | | | | | | | | | | |
| Including Internal Reference | | ±15 | ±30 | | | ±20 | | | ±20 | ppm of FSR/°C |
| Excluding Internal Reference | | ±4 | ±7 | | | ±10 | | | ±10 | ppm of FSR/°C |
| Unipolar Offset | | ±1 | ±3 | | | ±3 | | | ±3 | ppm of FSR/°C |
| Bipolar Offset | | ±7 | ±10 | | | ±10 | | | ±10 | ppm of FSR/°C |
| CONVERSION SPEED | | | | | | | | | | |
| Voltage Model (V)[5] | | | | | | | | | | |
| Settling Time to ±0.01% of FSR for FSR change 2k/Ω/500pF load) | | | | | | | | | | |
| with 10kΩ Feedback | | 3 | 4 | | 3 | 4 | | 3 | 4 | μs |
| with 5kΩ Feedback | | 2 | 3 | | 2 | 3 | | 2 | 3 | μs |
| For LSB Change | | 1 | | | 1 | | | 1 | | μs |
| Slew Rate | 10 | | | 10 | | | 10 | | | V/μs |
| Current Model (I) | | | | | | | | | | |
| Settling Time to ±0.01% of FSR | | | | | | | | | | |
| for FSR Change 10 to 100Ω Load | | 300 | | | 300 | | | 300 | | ns |
| for 1kΩ Load | | 1 | | | 1 | | | 1 | | μs |
| ANALOG OUTPUT | | | | | | | | | | |
| Voltage Models | | | | | | | | | | |
| Ranges—CBI | | ±2.5, ±5, ±10, +5, +10 | | | ±2.5, ±5, ±10, +5, +10 | | | ±2.5, ±5, ±10, +5, +10 | | V |
| —CCD | | | | | | | | | | V |
| Output Current | ±5 | | | ±5 | | | ±5 | | | mA |
| Output Impedance (dc) | | 0.05 | | | 0.05 | | | 0.05 | | Ω |
| Short Circuit Current | | | 40 | | | 40 | | | 40 | mA |
| Current Models | | | | | | | | | | |
| Ranges—Unipolar | −1.96 | −2.0 | −2.04 | −1.96 | −2.0 | −2.04 | −1.96 | −2.0 | −2.04 | mA |
| —Bipolar | ±0.96 | ±1.0 | ±1.04 | ±0.96 | ±1.0 | ±1.04 | ±0.96 | ±1.0 | ±1.04 | mA |
| Output Impedance—Bipolar | 2.5 | 3.2 | 4.1 | 2.5 | 3.2 | 4.1 | 2.5 | 3.2 | 4.1 | kΩ |
| —Unipolar | 5.0 | 6.6 | 8.2 | 5.0 | 6.6 | 8.2 | 5.0 | 6.6 | 8.2 | kΩ |
| Compliance | −2.5 | | +10 | −2.5 | | +10 | −2.5 | | +10 | V |
| Internal Reference Voltage ($V_R$) | +6.23 | +6.3 | +6.37 | +6.23 | +6.3 | +6.37 | +6.23 | +6.3 | +6.37 | V |
| Output Impedance | | 1.5 | | | 1.5 | | | 1.5 | | Ω |
| Max External Current[6] | | | +2.5 | | | +2.5 | | | +2.5 | mA |
| Tempco of Drift | | ±10 | ±20 | | ±10 | ±20 | | | ±10 | ppm of $V_R$/°C |
| POWER SUPPLY SENSITIVITY | | | | | | | | | | |
| ±15V ± 10%, 5V supply when applicable | | | ±0.002 | | | ±0.002 | | | ±0.002 | %of(FSR/%$V_S$) |
| ±12V at 5% | | | ±0.002 | | | ±0.002 | | | ±0.002 | %of FSR/%$V_S$ |
| POWER SUPPLY REQUIREMENTS | | | | | | | | | | |
| Rated Voltages | | ±15 | | | ±15 | | | ±15 | | V |
| Range | | | | | | | | | | |
| Analog Supplies | ±11.4[7] | | ±16.5 | ±11.4[7] | | ±16.5 | ±11.4[7] | | ±16.5 | V |
| Logic Supplies | | | | | | | | | V | |
| Supply Drain | | | | | | | | | | |
| +12, +15V | | 5 | 10 | | 5 | 10 | | 5 | 10 | mA |
| −12, −15V | | 14 | 20 | | 14 | 20 | | 14 | 20 | mA |
| +5V | | | | | | | | | | mA |
| TEMPERATURE RANGE | | | | | | | | | | |
| Specification | 0 | | +70 | −25 | | +85 | −55 | | +125 | °C |
| Operating | −25 | | +85 | −55 | | +125 | −55 | | +125 | °C |
| Storage | −25 | | +125 | −65 | | +150 | −65 | | +150 | °C |

NOTES
[1]Least Significant Bit.
[2]Adjustable to zero with external trim potentiometer.
[3]FSR means "Full Scale Range" and is 20V for the ±10V range and 10V for the ±5V Range.
[4]Gain and offset errors adjusted to zero at +25°C.
[5]$C_C$ = 0, see Figure 1a.
[6]Maximum with no degradation of specification, must be a common load.
[7]A minimum of ±12.3V is required for a ±10V full scale output and ±11.4V is required for all other voltage ranges.

Specifications subject to change without notice.

Specifications shown in boldface are tested on all production units at final electrical test. Results from those tests are used to calculate outgoing quality levels. All min and max specifications are guaranteed, although only those shown in boldface are tested on all production units.

DYTRAN INSTRUMENTS INC.

*Dynamic Transducers and Systems*

21592 MARILLA AVENU
CHATSWORTH, CA. 913
818·700·7818

# INSTRUCTION MANUAL

# MODEL 3100A

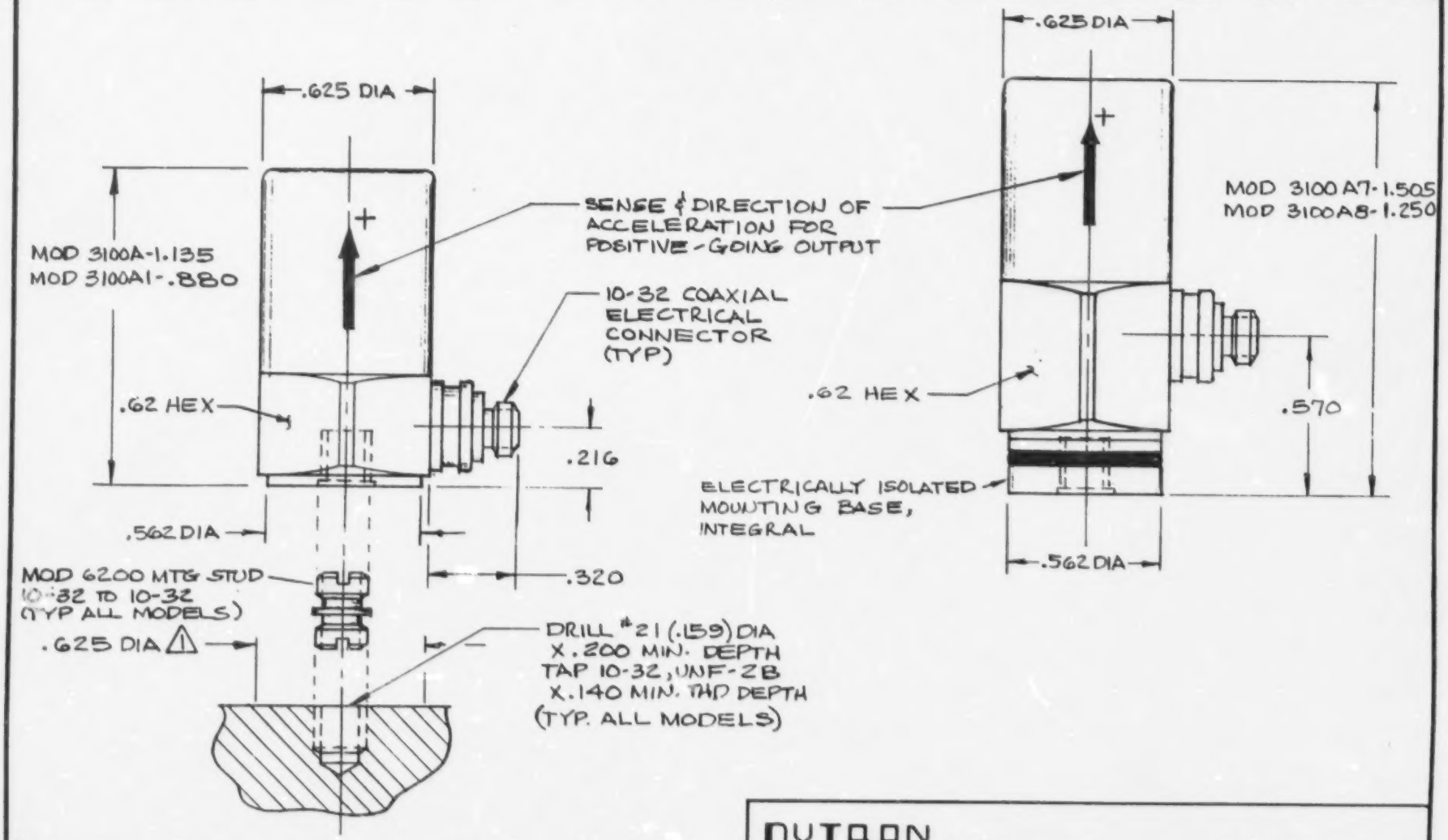
# HIGH SENSITIVITY

# VOLTAGE MODE ACCELEROMETER

SPECIFICATIONS

MODEL 3100A HIGH SENSITIVITY VOLTAGE MODE ACCELEROMETER

| SPECIFICATION | | |
|---|---|---|
| RANGE, F.S FOR ±5V out | ±50 | g |
| SENSITIVITY, ±2% | 100 | mV/g |
| FREQUENCY RANGE, 0.5db | 1-3500 | Hz |
| RESOLUTION | 2 | mg |
| LINEARITY | ±1 | %FS |
| OUTPUT BIAS VOLTAGE, (NOM.) | +11 | VDC |
| OUTPUT IMPEDANCE, MAX. | 100 | Ohms |
| TRANSVERSE SENSITIVITY, MAX. | 5 | % |
| TEMPERATURE RANGE | -60 to +250 | °F |
| THERMAL COEFF. OF SENSITIVITY | .03 | %/°F |
| DISCHARGE TIME CONSTANT | 0.5 | Sec. |
| MAX. VIBRATION | ±600 | g |
| MAX. SHOCK | 3000 | g |
| SIZE, DIA X HEIGHT | .62 X 1.09 | in. |
| WEIGHT | 57 | Grams |
| CONNECTOR, COAXIAL | 10-32 | Microdot |
| CASE MATERIAL, BASE/CAP | STAINLESS STEEL | |
| SEAL | WELDED/EPOXY | |
| SUPPLY CURRENT, FROM CONSTANT CURRENT SOURCE | 2 to 20 | mA |
| SUPPLY VOLTAGE | +18 to +30 | VDC |
| ACCESSORIES SUPPLIED | 1 | Mod 6200<br>Mtg. stud |




⚠ PREPARE SMOOTH, FLAT MOUNTING SURFACE OVER .625 DIA. AREA BY GRINDING, SPOTFACING, TURNING ETC. SURF. FLAT TO .001 TIR.

2. TORQUE ACCELS. IN PLACE WITH 20 TO 25 IN-LBS. IMPORTANT ! - DO NOT OVERTORQUE WHEN INSTALLING.

DYTRAN Instruments Inc. Buffalo, New York

| SCALE 2X | REVISIONS | BY | DATE |
|---|---|---|---|
| DATE 5-6-83 | | | |
| DWN | CKD | | |
| ENGD 5-6 | | | |

TITLE: OUTLINE/INSTALLATION DRAWING MODELS 3100A, 3100A1, 3100A7, 3100A8

NO. 127-3100

BRUNING 40-105

OPERATING INSTRUCTIONS

MODEL 3100A

VOLTAGE MODE ACCELEROMETER

## INTRODUCTION

The Dytran Model 3100A accelerometer is a Voltage Mode instrument which utilizes self-generating quartz crystals and a seismic mass to convert acceleration (vibration or shock)to an analogous,low impedance,electrical signal.

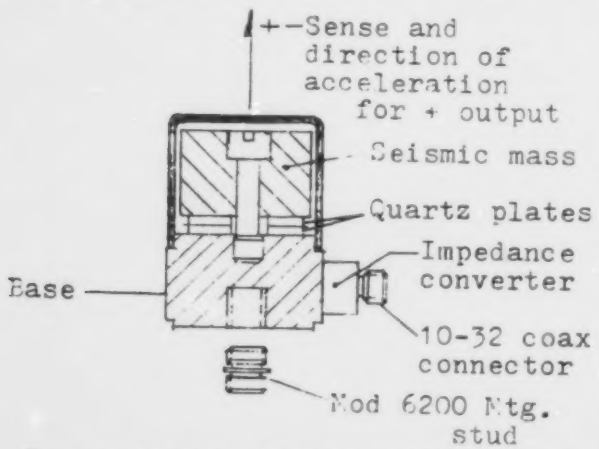
A self-contained IC MOSFET impedance converter operating in the source follower mode (2-wire system) transforms the high impedance level voltage signal generated by the quartz crystals to a low impedance signal able to drive long cables and operate directly into readouts such as oscilloscopes,digital VM's,recorders,etc.

The 3100A is attached to the test surface on machines and structures by preparing a flat surface and tapping a 10-32 threaded hole.

Connect accel. to power unit and power unit to readout using std. coaxial cables (or twin lead) and proceed with measurements.

## DESCRIPTION

Figure 1 is a representative cross-section drawing of the Mod. 3100A




Cross section,Model 3100A (1)

Figure 1

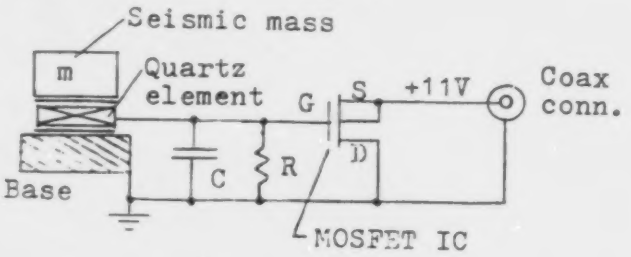
The seismic mass,made from a very dense Tungsten alloy,is tightly preloaded against the quartz crystals with a high compressive force.

Acceleration acting upon the base is transferred to the mass thru the crystals creating a force (F) equal to the acceleration (A) times the mass (m) in accordance with Newton's second law of motion:

$$F=mA \qquad \text{(Eq. 1)}$$

This force further compresses the crystals or releases some of the preload, depending upon the sense of the input acceleration, thereby generating a voltage which is impressed across the gate of the MOSFET IC and which is exactly proportional to the acceleration.

Because the IC amplifier is a unity gain amplifier, this same dynamic signal also appears at the source (output) terminal but reduced in impedance level by 10 orders of magnitude.( See Fig 2)




Electro/mechanical Schematic

Fig 2

The signal information is superimposed upon the approx +11 Volt DC bias level at the source terminal. This DC level is removed by the AC coupling in the power units and only the AC component appears at the "Output" connector jack.

The power to operate the IC built into the 3100A is supplied by simple,inexpensive power units, battery or line powered, which supply 2 to 20 mA of constant current( by current limiting diode or circuit) at a +18 to +30 Volt DC level.

The resistor R, shown in Fig.2 serves to bias the gate of the IC at it's proper operating point, ( at drain potential) and establishes the low frequency response of the accelerometer along with the total shunt input capacitance (C) in accordance with the following relationship:

$$f_{-3db} = \frac{.16}{R\,C} \qquad (\text{Eq.2})$$

where:

$f_{-3db}$ = Lower -3db Freq. (in Hz)

R = Resistance (R) (Ohms)

C = Capacitance(C) in Farads

Equation 2 defines the frequency at which the accelerometer sensitivity will be 3db down when compared to the 100 Hz reference frequency sensitivity.

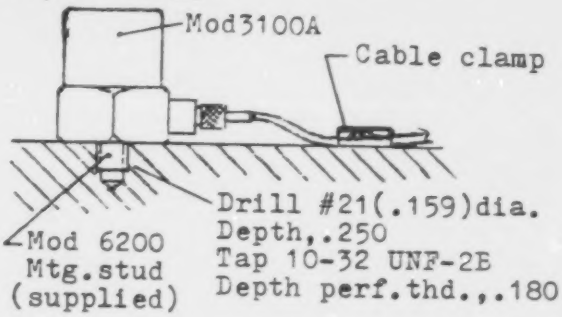
The -3db (lower) frequency for the Model 3100A is approx. 0.3 Hz.

The product RC (Eq, 2) is also the discharge time constant (TC) of the accelerometer, in Seconds.The TC for the Mod.3100A is 0.5 Sec.

INSTALLATION

To install the Mod.3100A it is necessary to have a flat mounting surface of approx. 3/4 in. dia.(see Fig.3) so that the base of the accelerometer is in intimate contact with the mounting surface over essentially all of it's area. this is especially important for good high frequency response.

The mounting surface must be flat within .0005 TIR to avoid straining the accel. base when it is torqued down.




Installation details

Figure 3

If it is necessary to machine the surface to obtain sufficient flatness,this can be done by spotfacing, grinding,turning and other machining operations.

In the center of the flat area,drill and tap a 10-32 hole in accordance with instructions given in Fig.3. Make sure that the hole is drilled perpendicular to the mounting surface to avoid uneven stressing of the mounting base.

After the hole is prepared,clean area carefully to remove all burrs and traces of cutting oil,etc.

Next,thread the Mod.6200 mounting stud into the base of the 3100A by hand until the stud seats on the flange located at the center of the stud. This flange prevents the stud from bottoming inside of the accel. where it could stress the base during mounting causing anomolous behaviour of the accelerometer.

After seating the stud, spread a small amount of silicone grease (Dow Corning DC-4 or equiv.) on the mating surfaces and thread the accel. stud into the mounting hole by hand until the base seats on the mounting surface. Check to see that

the mating surfaces are in intimate contactbefore proceeding with final torquing so the surfaces are not damaged by a burr or other foreign object interposed between the surfaces.

Now,torque the accel.to secure it to the surface with approx.20 to 25 in.lbs of torque on the hex only.

Try to maintain consistant mounting torque when mounting and remounting the accel. to avoid small errors in sensitivity and frequency response that could occur with great differences in mounting torque.

Connect the cable (Mod.6010 or equiv.) to the accel. making sure that the threaded locking collar is tight enough so the cable will not loosen under prolonged shock or vibration usage.

IMPORTANT

All accelerometers are more or less sensitive to cable motion since forces generated by such motion will strain the accel. base causing some spurious output from the crystals.

To minimize this effect,tie the cable down within approx. 1 inch of the accel.connector housing using an appropriate cable clamp or tie-down.

If the cable must be tied to an adjacent surface that is stationary with respect to the accel.,allow an ample strain relief loop.

Now connect the other end of the cable to the "Sensor" jack on the power unit (4102,4110,4114 or other) and switch power "ON".

Observe the Monitor voltmeter on the front panel of the power unit.

If the meter reads in the mid-scale region (normal) cables and connections are intact and the accel. amp is functioning. The system should now be ready for use.

Check for shorts in cables or connectors if the meter reads in the lower (short) region,and for open circuits if the meter reads full scale (open).

When "Normal" indication is obtained connect the "Output" of the power unit to the readout and allow several seconds for the coupling capacitors to charge, then proceed with measurements.

HIGH FREQUENCY RESPONSE

All piezoelectric accelerometers are essentially very rigid second order (spring/mass) systems with zero damping.

As a result, they will exhibit a rising characteristic vs.frequency with constant input amplitude.

The frequency at which the output will rise by approx.5% is approx.3500 Hz for the Mod.3100A. The accel. is useable above this freq. but it must be calibrated at the specific frequency of intended use because sensitivity deviations can become quite large beyond the calibrated freq.

CAUTIONS

1) Do not operate or store the 3100A at temperatures above +250 deg.F as to do so will damage the integral IC electronics.

2) Do not allow cables to hang loosely or vibrate unrestrained. Tie down as recommended.

3) If accel.is to be used in rapidly changing thermal environments,ask about thermal insulators available to minimize transient thermal effects.

4) Avoid dropping or striking against very rigid surfaces such as metals or concrete as the sensitive electronics can be damaged by careless handling.

## MAINTENANCE AND REPAIR

The welded/epoxy sealed construction of the Mod.3100A precludes field repair.

Should the mounting surface become nicked or deeply scratched, it can be redressed by careful wiping on a flat sheet of 400 grit emery paper on a surface plate.If surface damage is too extensive to clean up by this method, contact the factory for instructions on returning the instrument for repair.

Should any failure occur, contact the factory for assistance.

If it is necessary to return the unit for repair or replacement,be sure to include a short note describing the failure if possible and identifying the person to whom contact should be established regarding the repair or replacement.

Should the electrical connector become dirty, wipe it with a cloth dipped in a solvent such as Freon TF or equiv. Avoid solvents which will attack Teflon.

If a drop in low frequency response is noticed, wipe the connector and place the accelerometer in an oven set at +200 to +250 degrees F and allow to remain in the oven for at least one hour. Under certain conditions, moisture inside the accel can condense on the crystals or across the gate of the MOSFET causing a lowering of the TC and resulting in a degradation of low frequency response. The oven treatment will most often remedy such a condition.

DYTRAN INSTRUMENTS INC.

*Dynamic Transducers and Systems*

21592 MARILLA AVENUE
CHATSWORTH, CA. 91311
818·700·7818

# INSTRUCTION MANUAL

## MODELS 4110 AND 4114

## LINE POWERED CURRENT SOURCES

## FOR VOLTAGE MODE (VM) SENSORS

# SPECIFICATIONS

## MODEL 4110 (SINGLE CHANNEL) AND MODEL 4114(FOUR CHANNEL) CURRENT SOURCE

SPECIFICATIONS

| | | |
|---|---|---|
| Sensor Supply Current | 2 to 20, Adjustable | mA |
| Sensor Exitation Voltage | +24 | VDC |
| Voltage Gain | UNITY | |
| Front Panel Voltmeter, F.S. | +24 | VDC |
| Coupling Capacitor | 10 | uF |
| Coupling Time Constant | | |
| W/ 10 Megohm Load | 100 | Sec |
| W/ 1 Megohm Load | 10 | Sec |
| Lower -3db Frequency | | |
| W/ 10 Megohm Load | .0016 | Hz |
| W/ 1 Megohm Load | .016 | Hz |
| High Frequency Response | Determined by Sensor and Cable Length | |
| Noise, Wideband | 150 | uV RMS |
| Sensor Connector (s) | 10-32 Micro | Jack |
| Output Connector (s) | BNC | Jack |
| Power Cord | | |
| 110 V, 60 Hz Versions | 3-Wire W/Gnd. | 6 ft |
| 220 V, 50 Hz Versions | 2-Wire | 6 ft |
| Power Required | | |
| Model 4110 | 1.1 | VA |
| Model 4114 | 4.4 | VA |
| Size, H x W x D | 5.5 x 1.6 x 8.0 | In. |
| | 140 x 41 x 203 | mm |
| Weight | 32 | oz |
| | 907 | grams |

# OPERATING INSTRUCTIONS
# MODELS 4110 AND 4114
# ONE AND FOUR CHANNEL LINE POWERED
# CURRENT SOURCES

## INTRODUCTION

The DYTRAN Models 4110 and 4114 are line-operated power units for Voltage Mode (VM) Sensors or adaptor amplifiers (such as the DYTRAN Models 4500 and 4510) which require a constant current input and operate in the 2-wire mode.

The Model 4110 is a single channel unit while the Model 4114 can handle up to 4 sensors simultaneously.

These units can be used as desktop 'stand alone' instruments or can be removed from their outer cases and inserted into a rack adaptor by means of a captive thumbscrew at the bottom of the front panel. Up to ten units can be mounted into a 19 in. wide by 5¼ in. high rack, available from DYTRAN, our Model 4200.

The standard versions of these instruments operate from 110V/60Hz power . The 'E'(Export) versions such as E4110, operate from 220V/ 50Hz power mains.

## DESCRIPTION

These units contain a regulated +24VDC power supply. Operating from this power, constant current circuits supply 2 to 20 mA of constant current to the 'Sensor' jack(s) at the rear panel.

In VM Sensors, power (to operate the built-in amplifier) and signal are conducted over a single wire pair. The 4110 and 4114 decouple the signal from the approx. +12V sensor bias by means of 10uF coupling capacitors. These capacitors couple the signal to the 'Output' jacks at the rear panel. A front panel mounted voltmeter monitors the sensor bias voltage as a check on normal operation of the system.

A 4 position rotary switch on the front panel of the Mod. 4114 allows the selection of each channel for monitoring purposes.

## OPERATION

Refer to Fig. 1

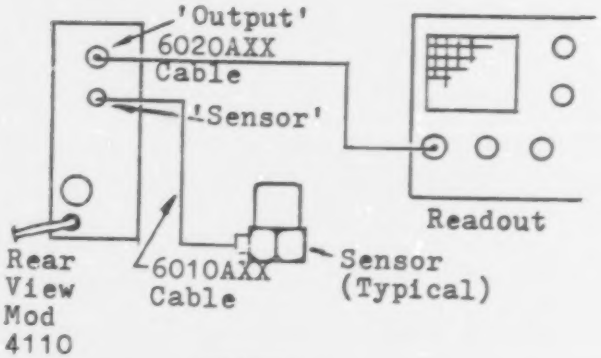



FIGURE 1
Typical System Interconnect

Connect the Sensor (or adapter Amp.) to the current source by means of a miniature coaxial cable such as the DYTRAN Mod. 6010AXX. Connect to 'Sensor' jack at rear panel.

Connect the 'Output' jack to the readout(oscilloscope, meter, recorder, etc.) using a BNC/BNC, RG 58/U cable such as the DYTRAN Mod. 6020AXX.

Plug line cord into the correct AC power main and move front panel toggle switch to 'ON' (up) position.

The front panel 'PWR' indicator lamp will glow and the voltmeter will indicate midscale reading if sensor is connected and will indicate full scale if no sensor is connected. For Model 4114, check that meter is monitoring the proper channel.

If these indications are not immediately present, unplug the unit and check the fuse. If it is blown replace with a ½Amp, 3AG fuse only.

Allow several minutes for the coupling capacitors to fully charge and for circuits to thermally stabilize, then proceed with measurements.

## BIAS MONITOR VOLTMETER

The front panel voltmeter monitors the output voltage of the constant current circuit(s) that provides power to the sensor amplifier.

With no sensor connected. the voltmeter will read the open circuit voltage of the circuit or +24 VDC., full scale on the meter.

By the same token, should an open occur in sensor cable or connectors, the meter will indicate full scale or 'open'.

The normal bias voltage of a VM sensor is approx +12 VDC which will result in a mid-scale or 'normal' reading.

Should sensor or cable be shorted, the meter will read to the extreme left or 'short' position.

In this manner, the voltmeter can become a useful trouble shooting tool.

## SETTING THE CONSTANT CURRENT

The constant current circuits in these units are set at the factory at 4 mA. This setting is sufficient for most applications and should not be changed unless necessary.

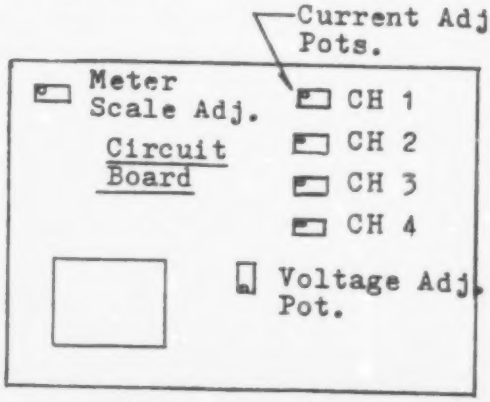
For certain situations such as when driving long sensor lines especially at high frequencies or with fast rise time pulses, it may be necessary to increase the drive current to maintain the integrity of the waveforms.

The constant current circuits are adjustable over the range of 2 to 20 mA and in no case should they be set beyond these limits.

To reset the value of sensor drive current, proceed as follows:

1) Remove the right hand (viewed from the front) side cover by removing the one securing screw toward the rear of the unit and sliding the cover rearward.

2) On the circuit board, locate the current setting potentiometers.( Refer to Fig. 2 )




Right Side View

FIGURE 2

Current and Voltage Adj. Pot. Locations

The single channel 4110 has only one current circuit in the 'CH 1' location while the 4114 has 4.

3) Connect a milliameter and a Zener diode in series across the 'Sensor' jack as shown in Fig.3 The Zener diode simulates the Sensor amplifier for more accurate setting of the current.

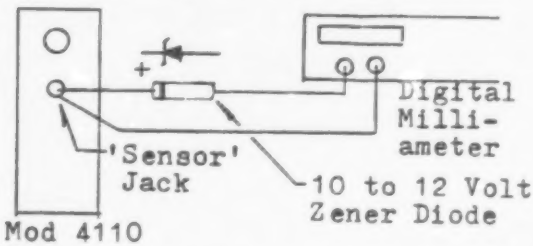



FIGURE 3

Circuit connections for current setting.

CAUTION

Use a non-metallic screwdriver when making any adjustments inside these units when power is applied. Touching the AC power input section with the hand could result in a dangerous electrical shock. Also, shorting solid state components with metal tools can destroy these components.

4) While monitoring the current, vary the setting of the current adj. pot. to set the current to the desired setting. Do not exceed 20 mA.

FAST PULSES AND LONG LINES

When driving long transducer lines with fast rise time pulses as with field blast or shock tube measurements, it has been discovered that it is often best to empirically determine the best drive current setting, that is, by trial and error since no two sets of line and load conditions are exactly identical.

Also, it has been found that in certain situations, it is necessary to match driving point and line impedances to avoid impedance mismatches which can cause reflections and other disturbing occurances, especially with pulses.

A low value resistor in series with the Sensor line (as shown in Fig. 4 can be useful in overcoming this difficulty.

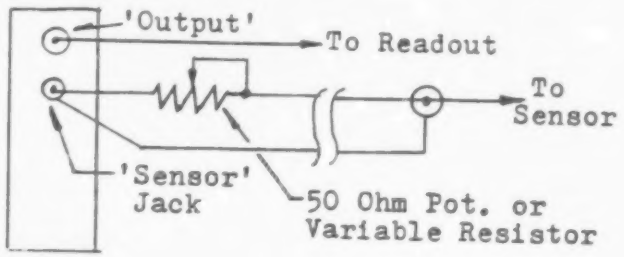



FIGURE 4

'Tuning'the line

By inserting a low value potentiometer in the line as shown in Fig. 4, and by emperically varying the value of this pot. along with the value of drive current, it will be possible to 'tune' the system for the best possible performance. As was previously mentioned, this can only be done through trial and error.

COUPLING TIME CONSTANT CONSIDERATIONS

The output of the Mods. 4110 &4114 are AC coupled with a 10 uF capacitor. This AC coupling could be the limiting factor in the low frequency response of the measurement system.

With a one megohm readout load, the coupling time constant(TC) is 10 Seconds. This yields a lower -3 db frequency of:

$$f_o = \frac{.16}{10} \quad \text{or} \quad .016 \text{ Hz} \quad \text{(Eq 1)}$$

This is probably sufficient for most applications, especially in vibration work. However, it will be found that for certain tasks such as when calibrating pressure transducers using quasi-static methods (possible with very long time constsnt transducers) it will be necessary to direct couple to the sensor output signal bypassing the AC coupling.

DYTRAN can supply power units that direct couple the ouput to the sensor (the Mod. 4115) but the Models 4110 & 4114 can also be connected to bypass the AC coupling. (Refer to Fig. 5)

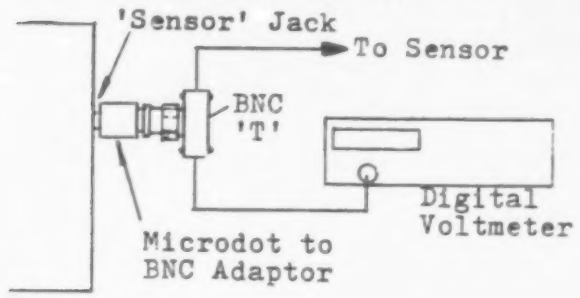



FIGURE 5

Direct coupling using 'T'

With this method of coupling the output signal in taken directly from the 'Sensor' line. It is important to note here that the DC bias at this point is approx. = to +12 Volts DC. Naturally, the read-out instrument must be capable of working with (or nulling out) this voltage offset. An opposing or 'bucking' voltage supply can be made using a 18 Volt battery and a potentiometer to provide a variable nulling voltage.

SETTING THE SUPPLY VOLTAGE

Under normal circumstances, it should never be necessary to have to adjust the power supply voltage in these power units. However, should it become necessary to do so, proceed as follows:

Locate the voltage adjust pot. on the circuit board. (Refer to Figure 2 for this location) With no Sensor connected to the unit, monitor the voltage (DC) at the 'Sensor' jack. Using the voltage adjust pot. set the voltage at this point to exactly 24 volts.

CAUTION

Any adjustments made inside these units with power applied can present a shock hazard. Use a non-metallic adjusting tool when making these types of adjustments.

MAINTENANCE AND REPAIR

Being entirely solid state devices no maintenance is required. Should it be necessary to replace a fuse unplug the unit and replace the fuse from the rear panel with a ½ Amp 3AG fuse only. If the fuse continues to blow, contact the factory for instructions in troubleshooting or returning the unit for repair.

There is no charge for evaluating even out of warranty repairs and no repair will be made without DYTRAN first contacting the customer for approval of repair costs if any.

All DYTRAN products are warranteed against defects in material and workmanship for a period of 6 months, starting on the date the item is accepted by the purchaser.

OPERATING INSTRUCTION SUPPLEMENT

OUTPUT ZERO CLAMP FOR

MODEL 4110 LINE POWERED

CURRENT SOURCE

## INTRODUCTION

The Model 4110 power unit now incorporates an output voltage zero clamp which may be switched in or out as desired. This guide explains what a zero clamp is and how it can be useful for certain types of measurements.

## ZERO CLAMP

Piezoelectric sensors are A.C. devices, i.e., zero voltage reference is not maintained during operation of the system. In many cases, this is not detrimental to system operation, as with most accelerometer applications.

However, in cases where essentially uni-directional repetative pulses are being measured, such as with impact force sensors or certain pressure pulse measurements, it is important that the baseline level of output voltage be maintained. The zero clamp prevents the level shifting that would normally occur in an A.C. coupled system, essentially clamping the baseline to zero volts.

## THEORY

The output voltage signal from an A.C. coupled sensor system, e.g., a force sensor measuring compressive force pulses, may look like figure 1., in the steady state.

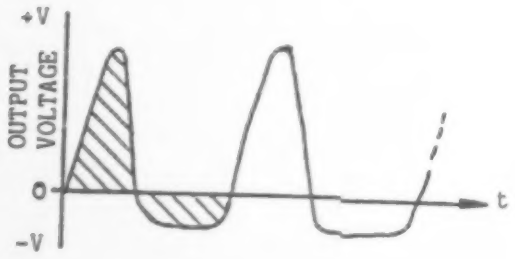



Figure 1.
Output signal, unclamped

As shown in Fig. 1., the voltage level will shift downward until the areas enclosed by the waveform (shaded areas) are equal above and below the zero baseline.

If the readout device is sensitive to absolute voltage level, such as with peak-reading voltmeters or certain data loggers, it is easy to see that the peak value of the waveform, shown in Fig. 1., will be in error if measured from the zero baseline.

To avoid this problem an output voltage zero clamp is incorporated in the Model 4110.

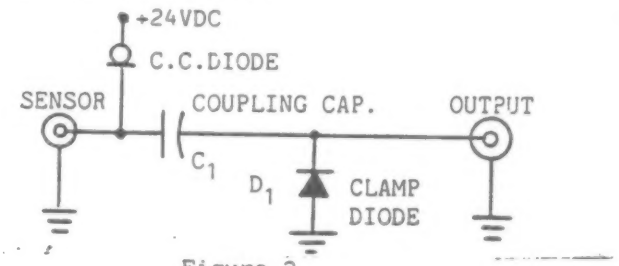



Figure 2.
Simple zero clamp

Figure 2. is a schematic of a simple zero clamp. The coupling capacitor $C_1$ blocks the +11V D.C. bias voltage from the sensor but allows the signal information to pass. The diode, $D_1$, prevents the output from going negative and effectively "lifts" the signal above the zero reference level.

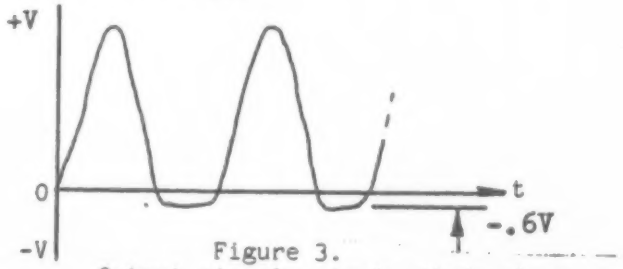



Figure 3.
Output signal, simple diode clamp

There is a problem with this arrangement, however. The forward voltage drop in the Diode, $D_1$, will not allow true zero clamping, i.e., the baseline will settle at .6 volts below the zero baseline as shown in Figure 3. This could be significant especially for low-level measurements. To remove this flaw, it is only necessary to return diode $D_1$ to a voltage point approx. .6 volts above ground instead of directly to ground.

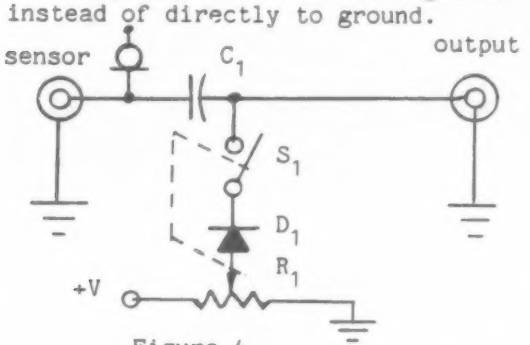



Figure 4.
Adjustable zero clamp
As in Model 4110

The arrangement shown in Figure 4. allows "fine tuning" of the zero clamp to exactly compensate for the diode forward drop characteristic to allow precise clamping of the waveform to zero as shown in Figure 5.

The latter circuit is employed in the Model 4110.

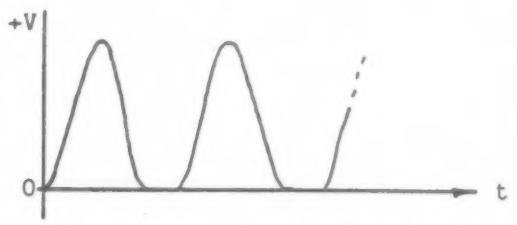



Figure 5.
Output signal
zero clamped

Potentiometer $R_1$ and switch $S_1$ are located at the rear panel of the Model 4110, see Figure 6.

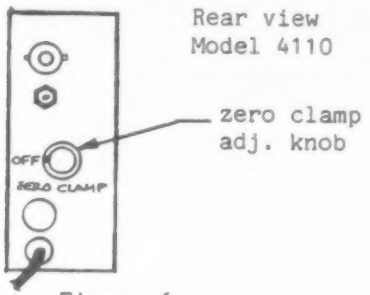



Figure 6.
Location of zero clamp
Adjust pot. and switch

To switch the zero clamp out, simply rotate the zero clamp adjusting knob fully counterclockwise past the detent. The unit will function as a normal A.C. couple power unit in this position.

To use the zero clamp, rotate the knob clockwise. The pot. may be used to adjust the waveform exactly to zero volts as shown in Figure 5.

## WARRANTY

DYTRAN INSTRUMENTS INC. WARRANTS ITS PRODUCTS AGAINST DEFECTS IN MATERIALS AND WORKMANSHIP FOR A PERIOD OF SIX MONTHS AFTER DELIVERY. DURING THE WARRANTY PERIOD, DYTRAN, AT ITS OPTION, WILL EITHER REPAIR OR REPLACE PRODUCTS WHICH PROVE TO BE DEFECTIVE.

## WARRANTY LIMITS

1.) IMPROPER OR INADEQUATE MAINTENANCE BY THE BUYER.

2.) UNAUTHORIZED MODIFICATION OR MISUSE.

3.) IMPROPER SITE PREPARATION OR MAINTENANCE.

## EXCLUSIVE REMEDIES

THE REMEDIES PROVIDED HEREIN ARE THE BUYERS SOLE AND EXCLUSIVE REMEDIES. DYTRAN SHALL NOT BE LIABLE FOR ANY DIRECT, INDIRECT, SPECIAL, INCIDENTAL, OR CONSEQUENTIAL TORT OR ANY OTHER LEGAL THEORY.

DYTRAN INSTRUMENTS, INC.
21592 MARILLA AVENUE
CHATSWORTH, CA. 91311
818·700·7818

DYTRAN INSTRUMENTS INC.
*Dynamic Transducers and Systems*

21592 MARILLA STREET
CHATSWORTH, CA 91311
(818) 700-7818
TWX 910-494-1941

# CALIBRATION CERTIFICATE
## VOLTAGE MODE ACCELEROMETER

MODEL 3100A NOMINAL SENSITIVITY 100 mV/g

SERIAL NO. 1157 RANGE, F.S. ± 50 g

REFERENCE SENSITIVITY
MEASURED AT 100 Hz, 1g RMS 102.0 mV/g

FREQUENCY RESPONSE (1)

| FREQUENCY (Hz) | SENSITIVITY DEVIATION (mV/g) |
|---|---|
| 20 | 101.7 |
| 30 | 101.8 |
| 50 | 101.9 |
| 100 | 102.0 |
| 300 | 102.1 |
| 500 | 102.9 |
| 1000 | 103.1 |
| 3000 | 103.2 |
| 3500 | 104.7 |

MAXIMUM TRANSVERSE SENSITIVITY <5 %

BIAS VOLTAGE 9.4 V

DISCHARGE TIME CONSTANT >1 sec

(1) This calibration was performed using the Back-to-Back Comparison Method per ISA S37.2. This calibration is traceable to the NBS test number 737/7324602.

CUSTOMER Durham Instruments P.O.# 6470

ORDER NO. 82462 DATE 2/2/87

CALIBRATION PERFORMED BY: D. Chang

CC8

DURHAM INSTRUMENTS
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# GFOF-3 series

GFC HAMMOND

**APPLICATION DATA**
1) Specifications
2) Outline & Mounting Dwg.
3) General User information.

**MODEL(S)**

| | |
|---|---|
| GFOF 3-5 | GFOF 3-24 |
| GFOF 3-12 | GFOF 3-28 |
| GFOF 3-15 | |

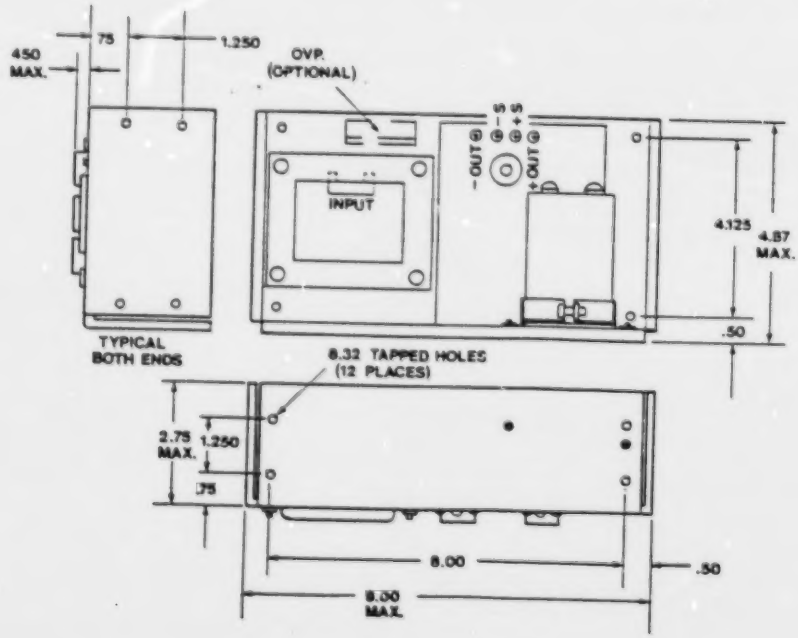
## FEATURES

- Engineered for greater reliability.
- Designed to comply with U.L. 478 and C.S.A. 22.2 specifications for data Processing equipment.
- Dual AC primary input: 115/230 VAC 47 - 63 Hz (user selectable).
- User replaceable IC'S.
- Remote sensing on most models.
- Fold back current limiting.
- Lo-flux transformers for minimum magnetic interference with CRT screens.
- Industry standard frame sizes for simplified second sourcing.
- Delivery from stock.
- Unconditionally guaranteed for two years.
- Manufacturing and serviced in the U.S.A. and Canada.

## SPECIFICATIONS

**Input:** 105-125 VAC/210-250 VAC 47-63Hz.
**Line regulations:** 0.05% over entire operating range.
**Load regulations:** 0.1% for no load to full load current.
**Output ripple & noise:** 1mV RMS/3mV peak-to-peak typical.
**Remote sensing:** On all models except GFOF-M series, GFOF-1D, GFDD-50, GFDD-100.
**Transient response:** No overshoot or undershoot on turn on turn off.
**Overload protection:** Foldback current limited, self restoring.
**Temperature co-efficient:** 0.2%/°C 0.002%/°C typical.
**Overvoltage protection:** optional.
**Cooling:** Convection cooled.
**Isolation:** Floating outputs must not exceed 500 VDC to ground.
**Ambient operating temperature:** Full rating from 0°C. to 50°C. Derate to 50% full rating @ 70°C.
**Construction:** Heavy gauge aluminum.
**Finish:** Clear anodized aluminum.

## OUTLINE & MOUNTING DRAWING




| Input Fuse Ratings Table For use @ | | |
|---|---|---|
| 115 | 3.0 A | Fast Blo |
| 230 | 1.5 A | Fast Blo |

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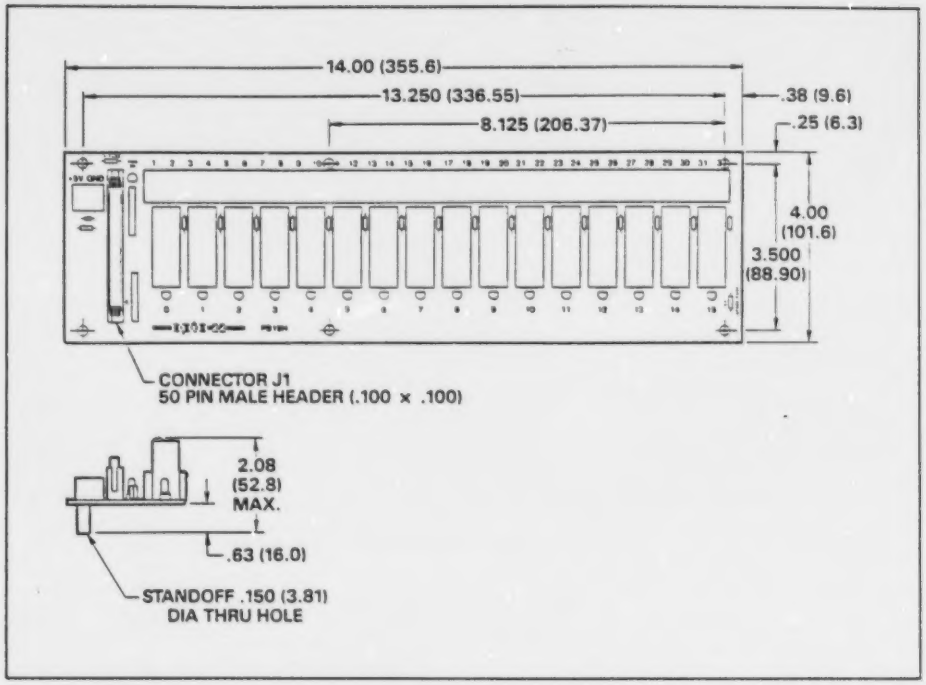
PB16H




| CONNECTOR J1 PINOUT | | | |
|---|---|---|---|
| PIN NO. | SIGNAL | PIN NO. | SIGNAL |
| 1 | +5V | 25 | MODULE 11 |
| 2-50 EVEN | COMMON | 27 | MODULE 10 |
| 3 | TEST | 29 | MODULE 9 |
| 5 | TEST | 31 | MODULE 8 |
| 7 | TEST | 33 | MODULE 7 |
| 9 | TEST | 35 | MODULE 6 |
| 11 | N/C | 37 | MODULE 5 |
| 13 | N/C | 39 | MODULE 4 |
| 15 | N/C | 41 | MODULE 3 |
| 17 | MODULE 15 | 43 | MODULE 2 |
| 19 | MODULE 14 | 45 | MODULE 1 |
| 21 | MODULE 13 | 47 | MODULE 0 |
| 23 | MODULE 12 | 49 | +5V |

opto 22

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# APPENDIX B

## CALCULATIONS

a) Refrigeration Capacity

b) A/D Resolutions for LVDT measurements

## REFRIGERATION CAPACITY

### DETERMINATION OF TOTAL AMOUNT OF HEAT TO BE REMOVED

ASSUMPTIONS:

| | | |
|---|---|---|
| 1. | Mass of Concrete | 38.2 kg |
| 2. | Specific heat of concrete | 837 J/kg.k |
| 3. | Mass of Water | 4.6 kg |
| 4. | Latent heat of water | 335 KJ/kg |
| 5. | Specific heat of water | 4,186 J/kg.k |
| 6. | Mass of Aluminum | 4 kg |
| 7. | Specific heat of aluminum | 896 j/kg.K |
| 8. | Mass of air | 0.8816 kg |
| 9. | Specific heat of air | 1,012 J/Kg.K |

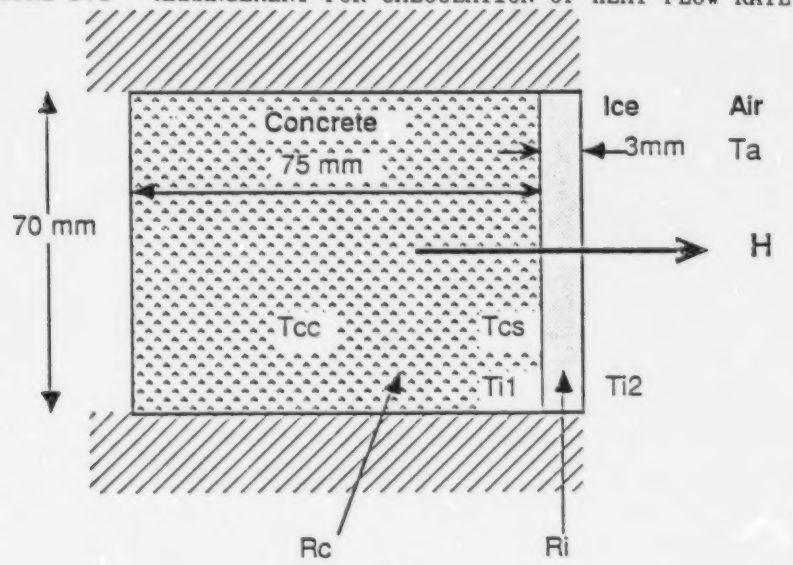
$\therefore$ Heat to be removed during freezing cycle 4.4°C → -17°C (21.4°K)

| | | | | | |
|---|---|---|---|---|---|
| a) | from concrete | (837 J/Kg) | (38.2 Kg) | (21.4°K) | = 684.23 KJ |
| b) | from aluminum | (896 J/Kg.K) | (4 Kg) | (21.4°K) | = 76.6 KJ |
| c) | from air | (1012 J/Kg.K) | (0.8816) | (21.4°K) | = 19.1 KJ |
| d) | from water | (4186 J/Kg.K) | (4.6) | (21.4°K) | = 412.0 KJ |
| | latent heat of water | (335 KJ/Kg) | (4.6 kg) | | = 1541 KJ |
| | | | | | 2732 KJ |

## ESTIMATION OF HEAT FLOW RATE

PROBLEM: Estimate the heat flow rate obtainable from concrete blocks in the situation depicted in Figure B.1.

FIGURE B.1 ARRANGEMENT FOR CALCULATION OF HEAT FLOW RATE




Thermal Resistance of Concrete: $R_c = \frac{L_c}{K_c A}$

Thermal Resistance of Ice: $R_I = \frac{L_I}{K_I A}$

Total Resistance: $R_T = R_C + R_I + R_{CONV}$

Heat flow: $q = \frac{\Delta T}{R_T}$

Convective Resistance at Surface: $RCONV = \frac{1}{h_c A}$

ASSUMPTIONS

1) For free convection $h_c = 12\ W/m^2\ °K$

2) For forced convection $h_c = 36\ W/m^2\ °K$

3) $K_c = 1.047\ W/m.k$

$K_I = 2.22\ W/m.k$

$A = 1m^2$ (6 boxes)

Assumptions Cont. $\Delta T = 10°C$

Total Heat to be removed = 2350 KJ

Calculations

$$R_c = \frac{0.035\ m}{(1.047)1} = 0.0334\ \frac{°K}{W}$$

$$R_I = \frac{0.003}{(2.22)1} = 0.0014\ \frac{°K}{W}$$

$$R_{CONV} = \frac{1}{(12)1} = 0.0833\ \frac{°K}{W\ free} \quad (0.0278\ °K/W\ forced)$$

$$R_T = 0.1181_{free}\ \frac{°K}{W}\quad R_{T\ forced} = 0.0626\ \frac{°K}{W}$$

$$\therefore q_{free} = 84\ W \qquad q_{forced} = 159\ W$$

Time Required for Cooling

1) free $\dfrac{2350 \times 10^3 J}{84\ J/S} = 7.7$ hrs

2) forced $\dfrac{2350 \times 10^3 J}{159\ J/S} = 4.1$ hrs

SENSITIVITY ANALYSIS OF HEAT FLOW RATE

ASSUMING AN OVERALL HEAT TRANSFER COEFFICIENT OF

1) 20 $W/m^2K$, and $\Delta T$ of 3.0 K during latent heat removal

$q = 20 * 30 = 600$ W

Need to remove 1540 KJ Latent heat of water

\+ 191 KJ Concrete cooling from 4°C to 0°C

1732 KJ

TIME REQUIRED: $\frac{1732 \times 10^3 \text{ J}}{600 \text{ J/S}} = 2886.4 \text{ S} = 48$ minutes

Note: Limiting refrigeration requirement of 600 W at -30°C (≃ -25F).

2. Assuming a $\Delta T$ of 10°C during the rest of the cycle

$q = 20 * 10 = 200$ W

need to remove 616 KJ [ total heat removal of 2348 KJ]

$\text{Time} = \frac{616E3}{200\ 60} = 51$ minutes

Total Time = 100 minutes

Refrigeration capacity 600 W ∴ -30°C

600 W x 3600 S = 2160 KJ/hr (2300 BTUH)

## CALCULATION OF HEAT LOSSES THROUGH CHAMBER WALLS

$k = 0.036\ W/m^2K$

Outside wall assumed to be at 20°C
Inner wall assumed to be at -20°C

$\Delta t = 40°C$

Dimensions of Chamber

| | |
|---|---|
| Height | 0.914 m |
| Width | 1.016 m |
| Length | 1.168 m |

Surface Area = (0.914) (1.016) x 2

+ (1.016) (1.168) x 2

+ (1.168) (0.914) x 2 = $6.366\ m^2$

Heat Losses = k A $\Delta$t

= 0.036 (6.366) 40

= 9.16 W

$$9.16\ W \times 3.63\ \frac{KJ/hr}{W} = 33.3\ KJ/hr$$

$\therefore$ Negligible loss through walls = 1 %

CALCULATION OF A/D RESOLUTION REQUIRED FOR LVDT MEASUREMENTS

LVDT SENSITIVITY = 200 mV/mm

RANGE = 3 mm

REQUIRED RESOLUTION = 0.005 mm

∴ Full Range Voltage from LVDT = 600 mV

12 Bit A/D has 4096 steps ∴ 0.0007 mm Resolution

10 Bit A/D has 1024 steps ∴ 0.0029 mm Resolution

8 Bit A/D has 256 steps ∴ 0.0117 mm Resolution

∴ A minimum 10 Bit A/D is required.

# APPENDIX C

# THERMAL ANALYSIS

# APPENDIX C - THERMAL ANALYSIS

## C.1 INTRODUCTION:

A thermal analysis of the concrete specimens subjected to temperature cycling was performed in order to determine the required conditions within the freeze-thaw machine test chamber. This analysis was performed using the general purpose thermo- elasto-plastic finite element package ASGARD. This program can handle up to 3 dimensional geometry; bar, brick, quadrilateral or axi-symmetric elements; convection, conduction or radiative boundary conditions; and transient or steady state conditions.

A calculation for the concrete specimens was performed using a two dimensional model with conduction and convection, and steady state conditions.

## C.2 ASSUMPTIONS:

The requirements of ASTM standard test method C-666-80 for thermal cycling of concrete specimens is as follows:

The temperature of the specimens shall be alternately lowered from 4.4°C to -17.8°C and raised from -17.8°C to 4.4°C in not less than two or more than four hours.

In order to carry out a two-dimensional time-step analysis of this procedure the following assumptions were made:

1) The dimensions and geometric layout of the concrete specimens used for this analysis are as shown in Figure C.1.

2) For the freezing cycle the initial conditions were the concrete specimen, water and containment box at 6°C and the surrounding air temperature at temperatures of -20°C and -25°C.

3) Two values of the convective heat transfer coefficient between the specimen box and the surrounding air were chosen to account for free or forced convection. These coefficients, together with the relevant properties of water, brass, steel and concrete are shown in Table C.1.

4) The latent heat obtained from freezing the water was included in the analysis by averaging this effect over a temperature range of 0°C to 17°C.

Figure C.1 Geometric Layout for Thermal Analysis

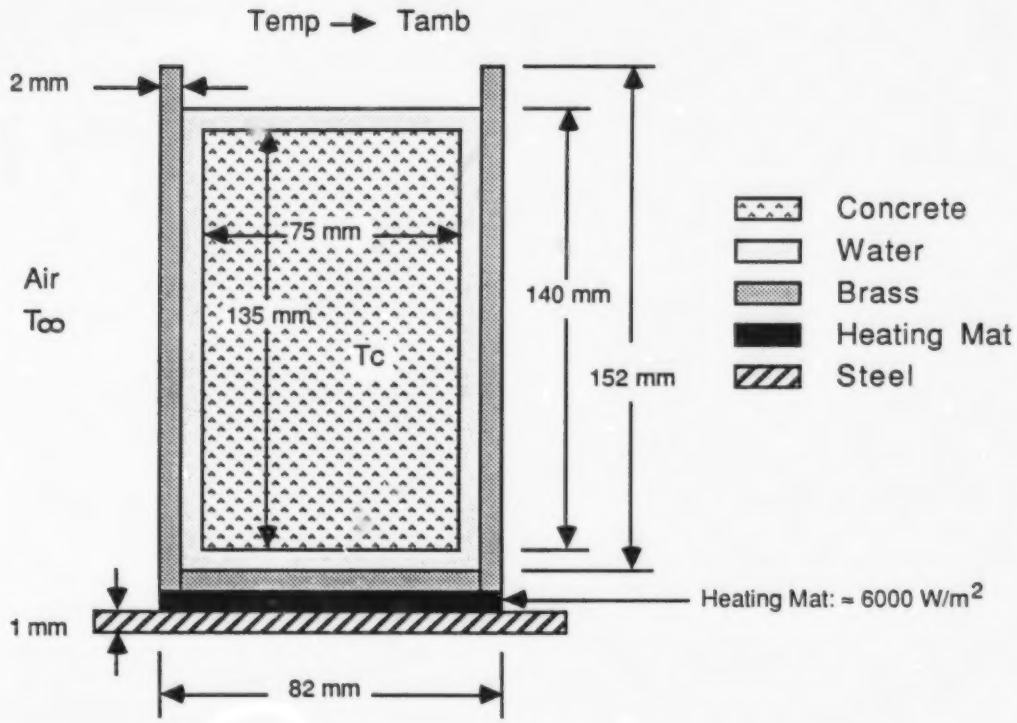


TABLE C.1.

THERMAL PROPERTIES OF MATERIALS

| | Sp.Heat (J/g°C) | Density ($g/cm^3$) | Conductivity (W/m°K) |
|---|---|---|---|
| Water | 4.197 | 1 | 0.561 |
| Brass | 0.377 | 8.5 | 106 |
| Steel | 0.48 | 7.8 | 50 |
| Concrete | 0.88 J/kg°C | 2106 $kg/m^3$ | 1.105 W/m°K |

LATENT HEAT OF WATER $3.35 \times 10^5$ J/KG

| | Volumetric Sp.Heat $J/mm^3°C$ | Thermal Conductivity (W/mm°C) |
|---|---|---|
| Water | 0.0042 | 0.000561 |
| Brass | 0.0032 | 0.106 |
| Steel | 0.0039 | 0.05 |
| Concrete | 1.85E-6 | 0.0011 |

5) Initial conditions for the heating cycle were to have the concrete, ice and containers temperature at -17°C and the ambient temperature held at values of -25°C, 0°C and +10°C.

6) Heat flow was permitted by means of conduction and convection at the air interface. No conduction was permitted, due to modelling constraints, in the water layer.

C.3 METHOD:

A two dimensional finite element method analysis was performed using the thermal analysis program ASGARD. The finite element mesh which was constructed for this program is shown in Figure C.2. Parametric variations of ambient temperature, and surface-air convection rate were conducted. In addition the effect of assuming the top surface to be either water or ice was investigated. A total of five runs were made to indicate the sensitivity of the analysis to changes in these parameters during the cooling portion of the cycle. The relevant parameters are shown in Table C.2.

During the heating portion of the cycle heat was supplied by a heat source located at one of two locations either on the bottom or the side of the container box. Power was varied as indicated in Table C.2 to determine the power requirement to meet the cycle. The ambient temperature of the air was also varied.

C.4 RESULTS:

The output from the relevant runs of the concrete model using the finite element program is shown graphically in Figures C.3 - C.12. As indicated Figures C.3 - C.7 are cooling curves while C.8 - C.12 are heating curves. The ambient conditions shown for these curves represent bounds between which it is believed the actual conditions in the freezer will lie. These results, show that both the chamber temperature and the convective heat transfer rate from the concrete have a significant effect on the results. The longest cooling time is in excess of 120 min. at -20°C with free convection (cycle 3). Changing the ambient conditions to forced convection such as would occur if a fan was placed in the chamber reduced the cooling time from 0° - -17°C to 58 min (cycle 5) while reducing the chamber temperature to -25°C further reduced this cooling time to about 36 min. (cycle 4). The cooling time from 6°C to 0°C has been calculated separately as this would likely occur before the water surrounding the concrete had frozen completely, thus different heat transfer rates would apply. The results from this calculation are shown in Figure C.3 and indicate that under the conservative conditions of -20°C with free convection about ten minutes should be added to the previous figures to obtain the total cooling times.

FIGURE C.2

FINITE ELEMENT MESH

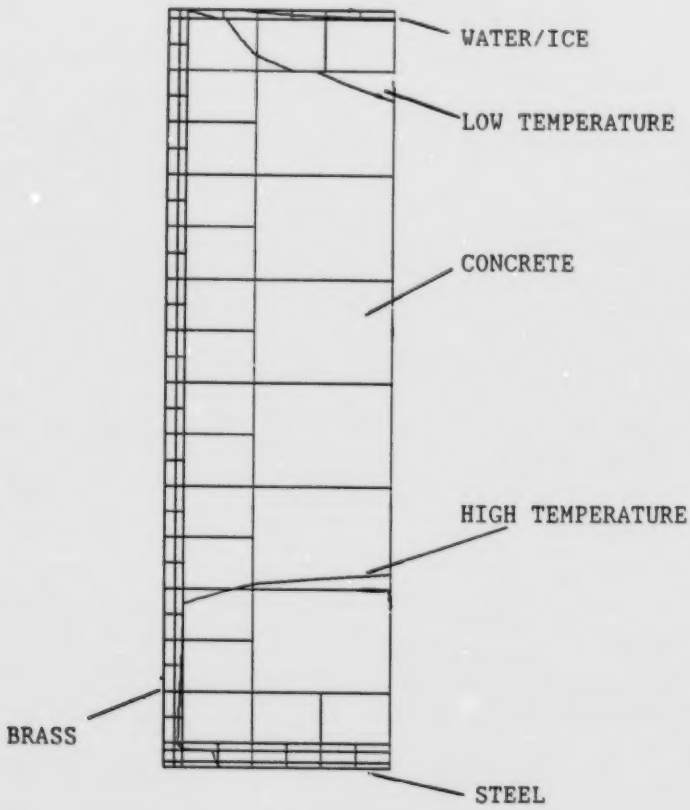


TABLE C.2

PARAMETRIC VARIATION OF AMBIENT TEMPERATURE,
SURFACE CONVECTION, AND AMBIENT TEMPERATURE

a) Cooling Analysis

| | Initial $T_{concrete}$ °C | $T_{ambient}$ °C | Surface Convection Coefficient | Temp.Range for Latent Heat Absorption | Top Surface of Concrete |
|---|---|---|---|---|---|
| 1 | 6 | -25 | 12 | +6°C → -17°C | Water |
| 2 | 6 | -25 | 12 | 0°C → -17°C | Ice |
| 3 | 6 | -20 | 12 | 0°C → -17°C | Ice |
| 4 | 0 | -25 | 30 | 0°C → -17°C | Ice |
| 5 | 0 | -20 | 30 | 0°C → -17°C | Ice |

b) Heating Analysis

| | Initial $T_{concrete}$ °C | $T_{ambient}$ °C | Surface Convection Coefficient $hc/WM^2$ | Heating Power Applied $kW/m^2$ | |
|---|---|---|---|---|---|
| 1 | -17 | -25 | 12 | 6 | |
| 2 | -17 | 0 | 12 | 3 | |
| 3 | -17 | 0 | 12 | 1.25 | |
| 4 | -17 | +10 | 12 | 1.25 | |
| 5 | -17 | 0 | 12 | 0.4* | Applied on side of containment box |

FIGURE C.3

CONCRETE COOLING CYCLE
T amb=-25 C h=12 W/m^2
Latent heat absorbed over +6 to -17 C
Water on top surface

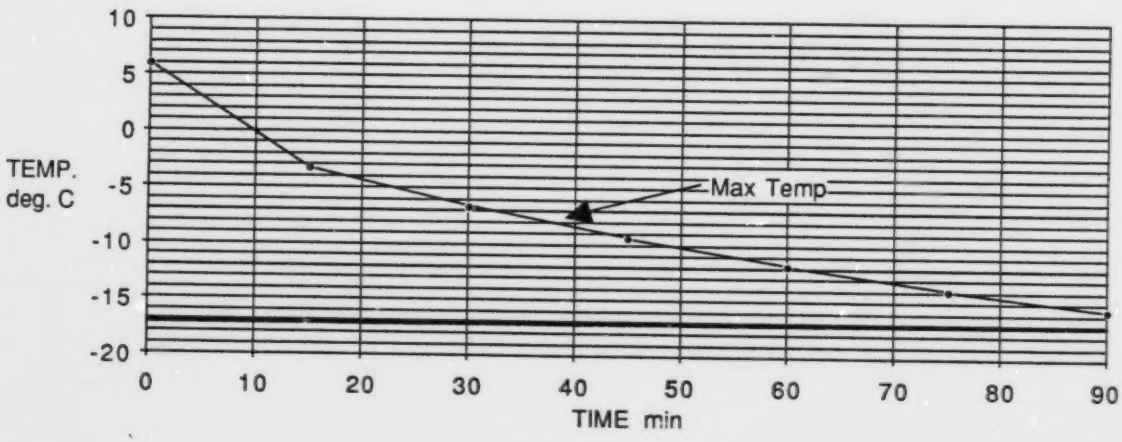


FIGURE C.4

CONCRETE COOLING CYCLE
T amb=-25 C h=12 W/m^2
Latent heat absorbed over 0 to -17
Ice on top surface

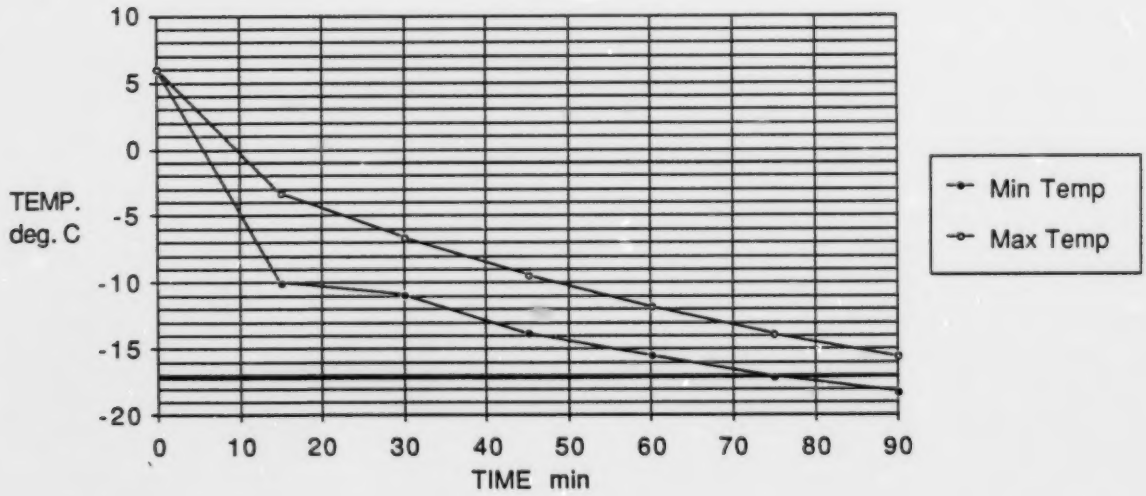


FIGURE C.5

CONCRETE COOLING CYCLE
T amb=-20 C h=12 W/m^2
Latent heat absorbed over 0 to -17
Ice on top surface

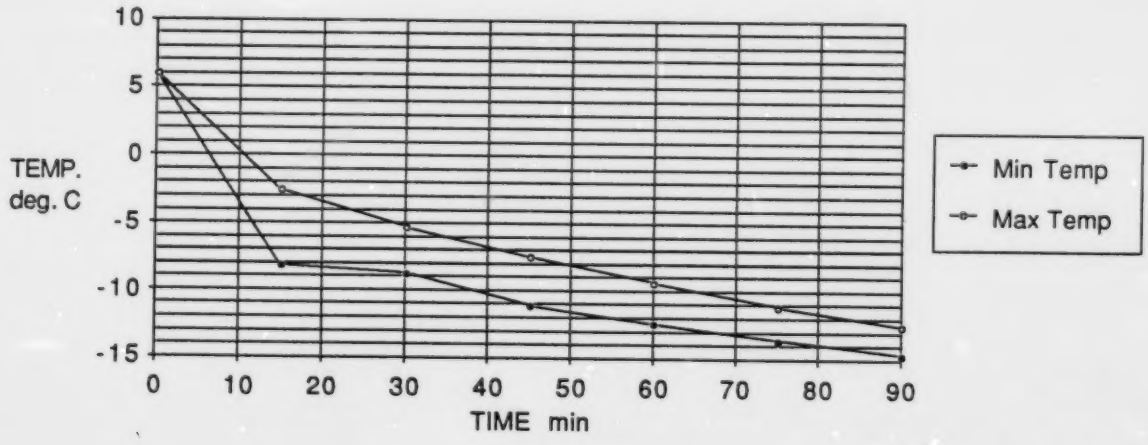


FIGURE C.6

CONCRETE COOLING CYCLE
T amb=-25 C h=30 W/m^2
Latent heat absorbed over 0 to -17
Ice on top surface

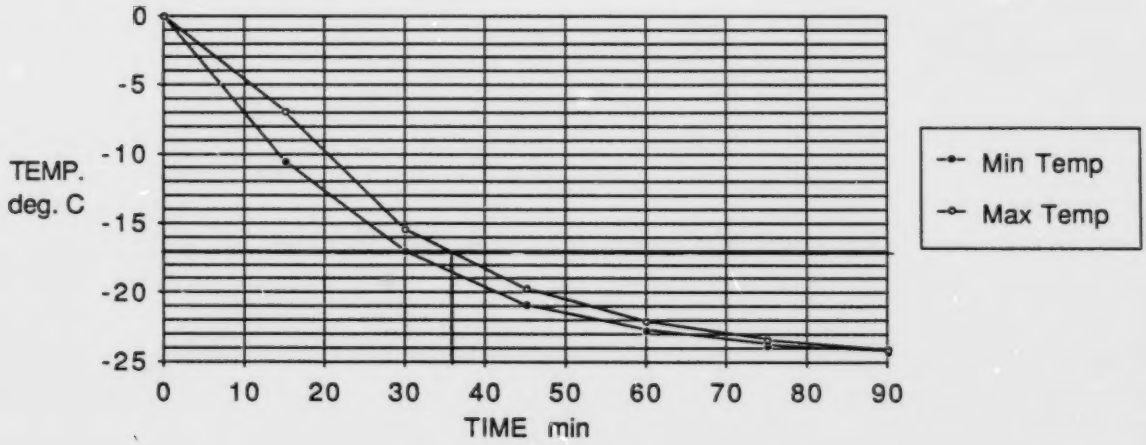


FIGURE C.7

CONCRETE COOLING CYCLE
T amb=-20 C  h=30 W/m^2
Latent heat absorbed over 0 to -17
Ice on top surface

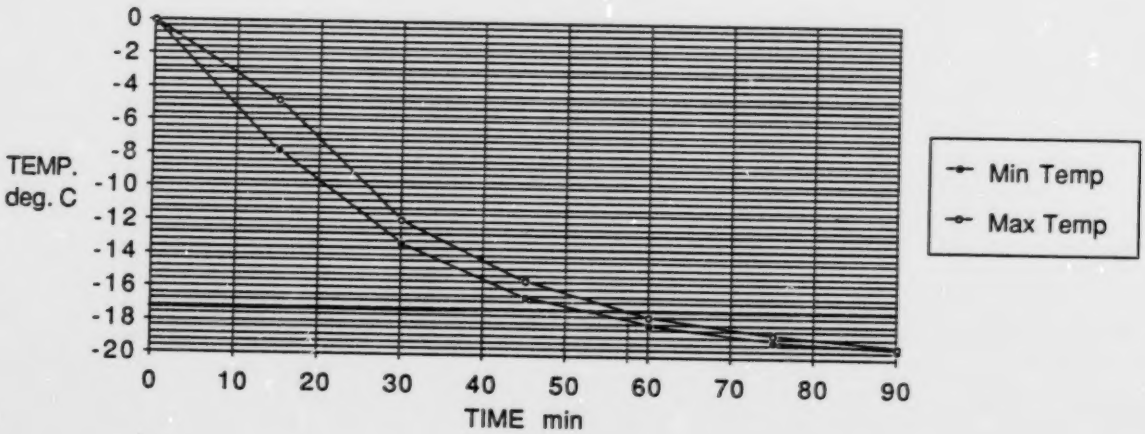


FIGURE C.8

T-amb =-25 C h=12 W/m^2
Latent heat absorbed -17 to +6 C
Heating power =6 kW/m^2

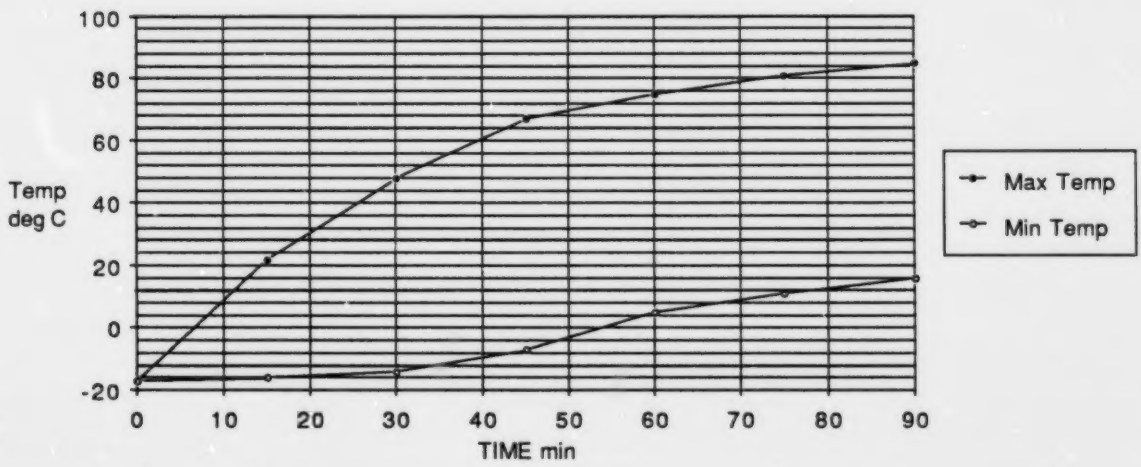


FIGURE C.9

T-amb =0 C h=12 W/m^2
Latent heat absorbed -17 to +6 C
Heating power =3 kW/m^2

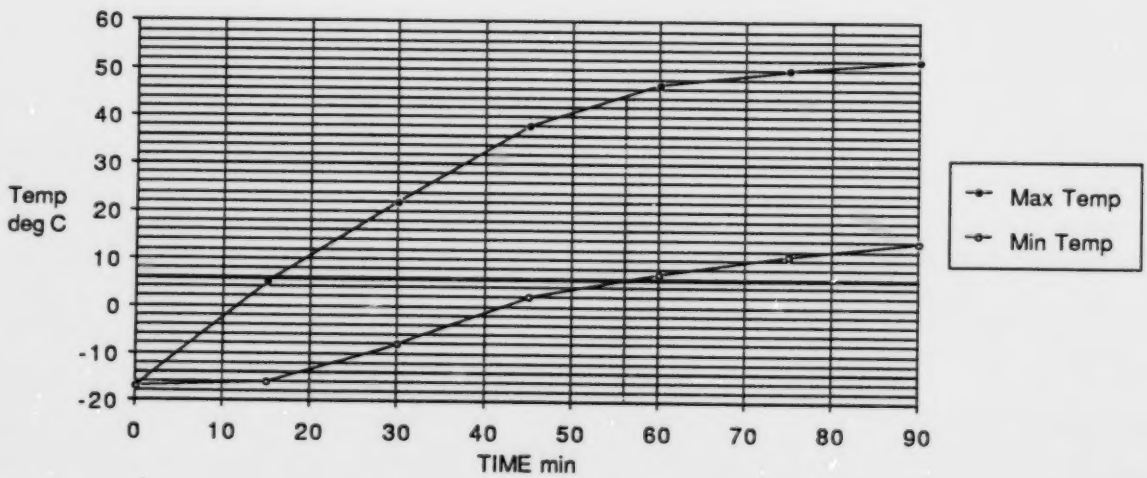


FIGURE C.10

T-amb =0 C h=12 W/m^2
Latent heat absorbed -17 to +6 C
Heating power =1.25 kW/m^2

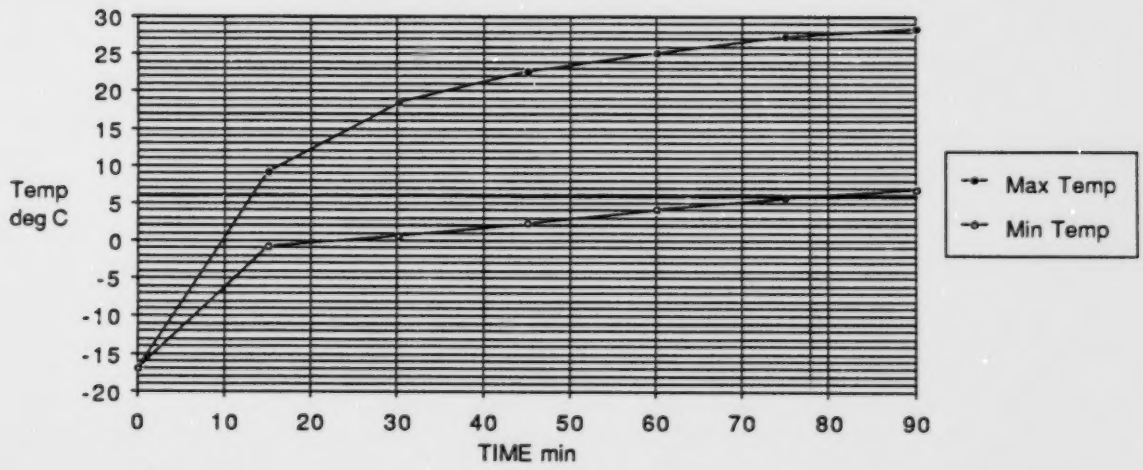


FIGURE C.11

T-amb =+10 C h=12 W/m^2
Latent heat absorbed -17 to +6 C
Heating power =1.25 kW/m^2

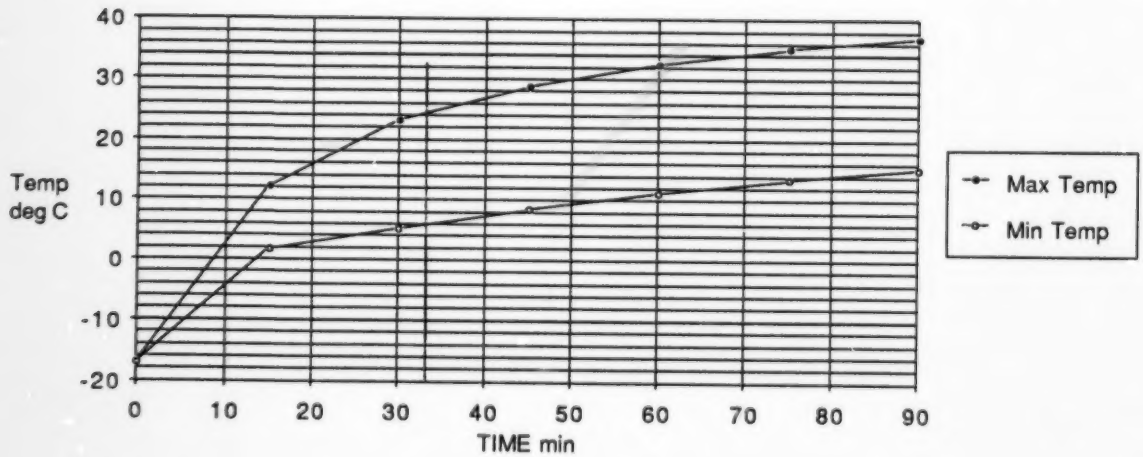
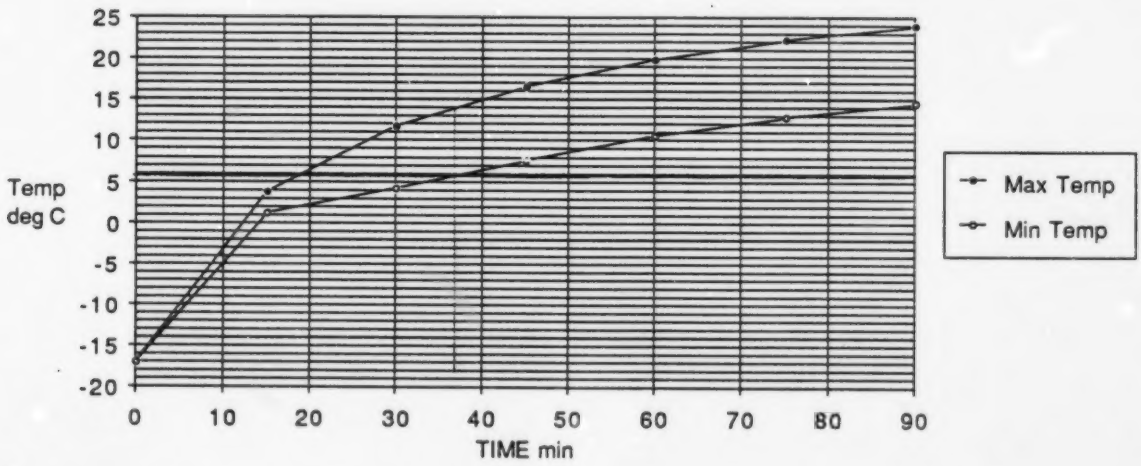


FIGURE C.12

T-amb =0 C h=12 W/m^2
Latent heat absorbed -17 to +6 C
Heating power =0.4 kW/m^2



The results of this analysis show that to obtain a target cooling time of 90 minutes with forced convection, a chamber temperature of -20°C is sufficient. If free convection must be relied upon then the chamber temperature must be less than -25°C. The difference between the maximum and minimum temperatures within the concrete samples has been found to be less than 5°C during the cooling part of the cycle. This is illustrated by Figure C.7 which shows the most extreme cooling cycle. After fifteen minutes of cooling from 0°C the maximum and minimum temperatures are -4.4°C and -8°C, respectively. This can be compared to the 20° temperature difference permitted by the ASTM standard.

The results of the analysis of the heating cycle are shown in Figures C.8 - C.12 for a variety of ambient conditions and heater power inputs. In Figure C.12 the heater input has been applied to the side of the specimen but in all other cases the heat is applied to the bottom of the specimen. Both ambient temperature and heater power have been varied to obtain a range of solutions showing heating time and temperature variation within the specimen.

When considering these results the fact that convective heat transfer in the water surrounding the specimens was not permitted should be kept in mind. This is not accurate as convective mixing would occur. The result of convection would be to reduce the temperature range in the specimen and thus decrease the time required for heating.

The most obvious results is that the ambient temperature in the chamber has a major effect on both the temperature range and the time required for heating. With 6 $W/m^2$ at -25°C ambient it would not be possible to raise the minimum temperature of the specimen to 6°C although the local hot spot near the heater would reach 80°C. With higher ambient temperatures of 0° and +10°C heating times drop to 78 and 33 minutes respectively despite a reduced heat input of 1.25$W/m^2$ as shown in Figures C.10 and C.11 respectively. It would appear that increasing the ambient temperature of the chamber will decrease both the time required to heat the concrete and the range of temperatures within the concrete. Placing the heat input at the sides of the concrete would appear to reduce the temperature variation further as indicated in Figure C.12, however, during this test the specific heat input was also reduced to 0.4 $W/m^2$. The total heat input was maintained.

Based on the heating cycle analysis it would appear that the heat input should be about 1 $W/m^2$ to avoid large temperature gradients. The effect of convective stirring within the water will also most likely lower the thermal gradients. The ambient temperature appears to have a large effect on the heating rate, and should be permitted to rise as much as possible. Heating times will likely be in the order to 30 - 45 minutes.